Global Space-based Inter-Calibration System (GSICS)

Mitchell D. Goldberg,
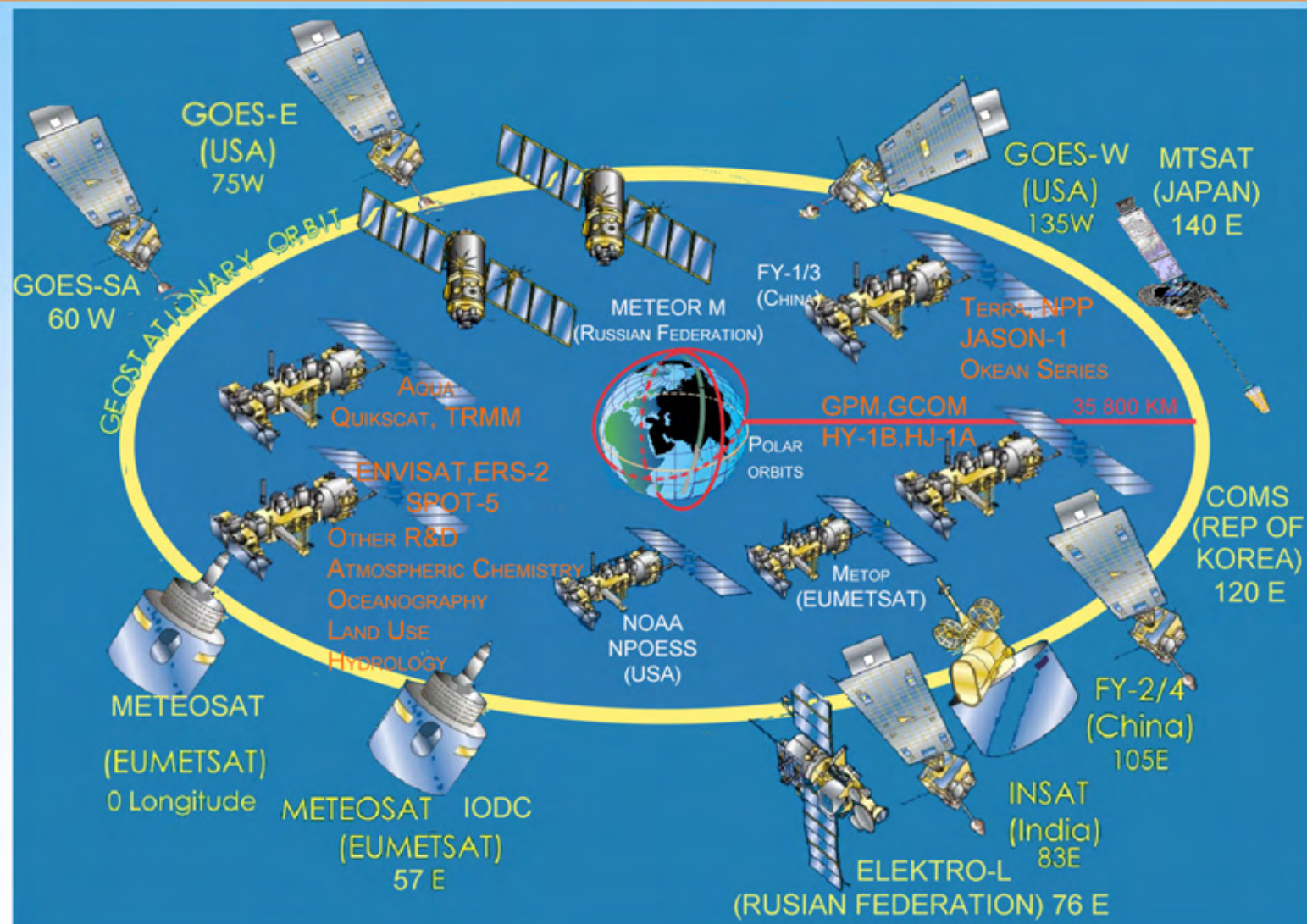
GSICS Exec Panel Chair
NOAA/NESDIS
Chief, Satellite Meteorology and Climatology Division

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Space-Based component of the Global Observing System (GOS)

- The intergovernmental *Group on Earth Observations* (GEO) is leading a worldwide effort to build a Global Earth Observation System of Systems (GEOSS)

- Satellite component is addressed by the Committee on Earth Observation Satellites (CEOS)

- CEOS includes space /satellite agencies and WMO

- Two key international cal/val programs
  – CEOS Working Group on Cal/Val (WGCV)
  – WMO GSICS

What is GSICS?

- Global Space-based Inter-Calibration System (GSICS)

- Part of WMO Space Programme
  - GSICS Implementation Plan and Program formally endorsed at CGMS 34 (11/06)

- NOAA is the coordination center and chairs the GSICS executive panel

- Goal - Enhance calibration and validation of satellite observations and to intercalibrate critical components global observing system

Organizations contributing to GSICS

- NOAA (& SSEC/CIMSS)
- NIST
- NASA
- EUMETSAT
- CNES
- CMA
- JMA
- KMA

GSICS current focus is on the intercalibration of operational satellites, and makes use of key research instruments such as AIRS and MODIS to intercalibration the operational instruments

Motivation

- Demanding applications require well calibrated and intercalibrated measurements

  - Climate Data Records
  - Radiance Assimilation in Numerical Weather Prediction
  - Data Fusion

- Growing Global Observing System (GOS)
  - GEOSS

Nine Societal Benefits

- Improve Weather Forecasting
- Reduce Loss of Life and Property from Disasters
- Protect and Monitor Our Ocean Resource
- Understand, Assess, Predict, Mitigate and Adapt to Climate Variability and Change
- Support Sustainable Agriculture and Forestry and Combat Land Degradation
- Understand the Effect of Environmental Factors on Human Health and Well-Being
- Develop the Capacity to Make Ecological Forecasts
- Protect and Monitor Water Resources
- Monitor and Manage Energy Resources

Science Requirements for GEOSS to meet the 9 societal benefits:

- Satellite Intercalibration & Sensor characterisation

- Data Fusion & Integrated Products, including CDRs

- Data Assimilation & Modeling

GSICS Objectives

- To improve the use of space-based global observations for weather, climate and environmental applications through operational inter-calibration of satellite sensors.

- Improve global satellite data sets by ensuring observations are well calibrated through operational analysis of instrument performance, satellite intercalibration, and validation over reference sites

- Provide ability to re-calibrate archived satellite data with consensus GSICS approach, leading to stable fundamental climate data records (FCDR)

- Ensure pre-launch testing is traceable to SI standards

Building Blocks for Satellite Intercalibration

- ## Collocation
  - Determination and distribution of locations for simultaneous observations by different sensors (space-based and in-situ)
  - Collocation with benchmark measurements

- ## Data collection
  - Archive, metadata - easily accessible

- ## Coordinated operational data analyses
  - Processing centers for assembling collocated data
  - Expert teams

- ## Assessments
  - communication including recommendations
  - Vicarious coefficient updates for "drifting" sensors

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Other key building blocks for accurate measurements and intercalibration

- Extensive pre-launch characterisation of all instruments traceable to SI standards

- Benchmark instruments in space with appropriate accuracy, spectral coverage and resolution to act as a standard for inter-calibration

- Independent observations (calibration/validation sites – ground based, aircraft)

GSICS Organization

GSICS Executive Panel

GRWG

GDWG

Calibration Support Segments (reference sites, benchmark measurements, aircraft, model simulations)

CSS

GCC

GPRC

Coordination Center

Regional Processing Research Centers at Satellite Agencies

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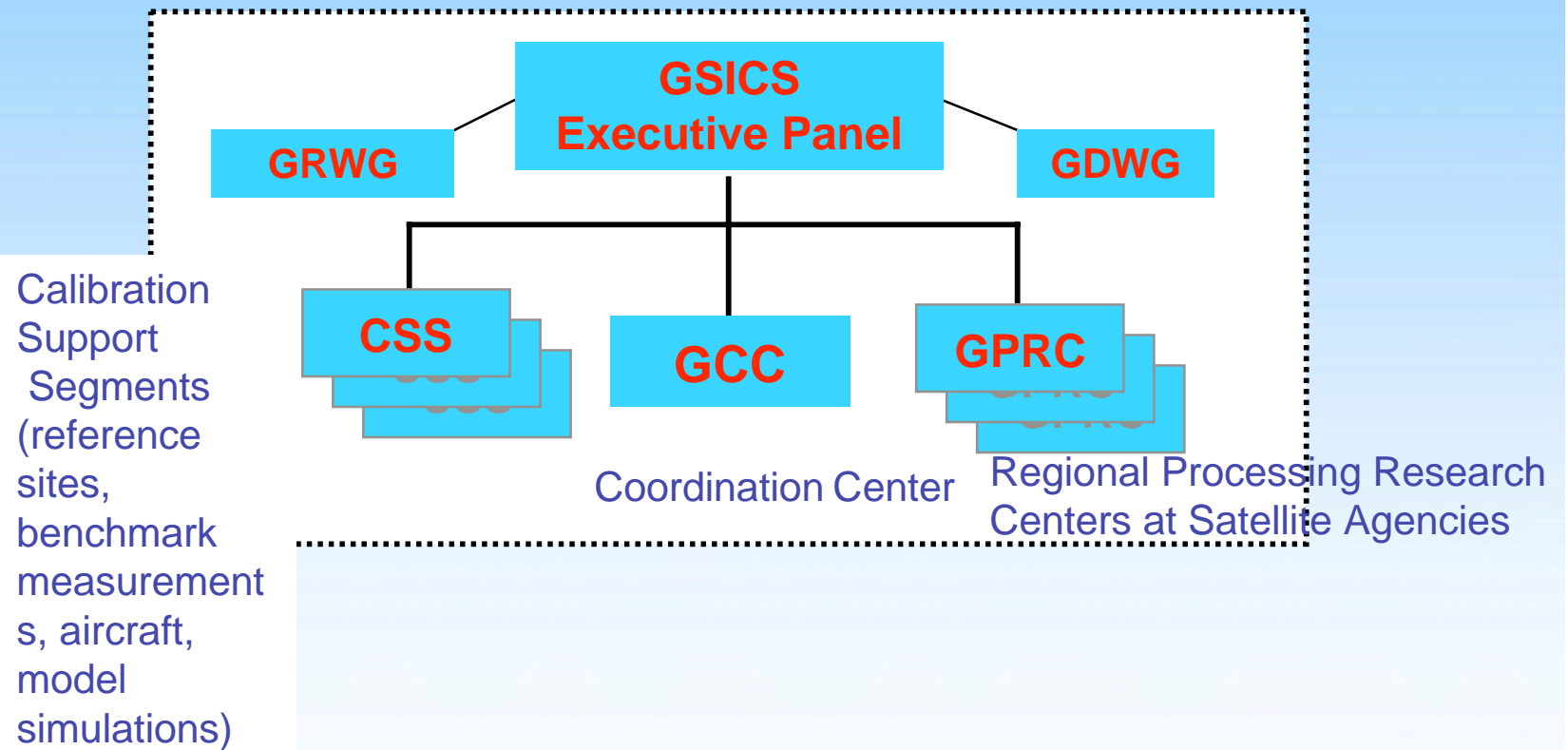
GSICS Components

- GSICS Executive Panel – reps from each satellite agency
  - Priorities, objectives and agreements
- GSICS Coordination Center (GCC) – NESDIS/STAR
  - Transmit intercalibration opportunities to GPRCs
  - Collect data from the GPRCs and provide access
  - Quarterly reports on performance
- GSICS Processing and Research Centers (GPRCs)
  - Satellite agencies
  - Activities:
    - Pre-launch calibration
    - Intersatellite calibration
    - Supporting research

Calibration Support Segments (CSS)

- The GSICS Calibration Support Segments (CSS) will be carried out by participating satellite agencies, national standards laboratories, major NWP centers, and national research laboratories. CSS activities are:

- **Prelaunch Characterisation,** reference instruments, SI traceability
- **Earth-based reference sites,** such as stable desert areas, long-term specially equipped ground sites, and special field campaigns, will be used to monitor satellite instrument performance.
- **Extra-terrestrial calibration sources,** such as the sun, the moon, and the stars, will provide stable calibration targets for on-orbit monitoring of instrument calibration
- **Model simulations** will allow comparisons of radiances computed from NWP analyses of atmospheric conditions with those observed by satellite instruments
- **Benchmark measurements** of the highest accuracy by special satellite and ground-based instruments will help nail down satellite instrument calibrations

GSICS Executive Panel

Affiliation	Last Name	First Name
CMA	Lu	Naimeng
CNES	Renaut	Didier
EUMETSAT	Schmetz	Johannes
JMA	Kurino	Toshiyuki
KMA	Ou	Mi-Lim
NOAA	Goldberg	Mitch (Chair)
WMO	Lafeuille	Jérôme

GSICS Coordination Center

Affiliation	Last Name	First Name
NOAA	Iacovazzi, Jr.	Bob (Deputy Director, GQ Co-Editor)
NOAA	Li	Yaping
NOAA	Sullivan	Jerry T. (GQ Co-Editor)
NOAA	Weng	Fuzhong (Director)

GSICS Data Working Group

Affiliation	Last Name	First Name
CMA	Rong	Zhiguo
EUMETSAT	Gaertner	Volker (Chair)
JMA	Matsumoto	Takanori
NOAA	Barkstrom	Bruce
NOAA	Jelenak	Aleksandar
WMO	Lafeuille	Jerome

GSICS Research Working Group

Affiliation	Last Name	First Name
CIMSS	Gunshor	Matt
CMA	Zhang	Peng
CNES	Blumstein	Denis
CNES	Henry	Patrice
EUMETSAT	König	Marianne
EUMETSAT	Van de Berg	Leo
JMA	Tahara	Yoshihiko
KMA	Ahn	Myoung-Hwan
KMA	Chung	Sung-Rae
KMA	Sohn	Byung-Ju
NASA	Doelling	David
NASA	Minnis	Patrick
NASA	Nguyen	Louis
NASA	Xiong	Jack
NIST	Datla	Raju
NIST	Johnson	Carol
NOAA	Beck	Trevor
NOAA	Cao	Changyong
NOAA	Flynn	Larry
NOAA	Knapp	Ken
NOAA	Privette	Jeff
NOAA	Wang	Likun
NOAA	Wu	Fred (Chair)
NOAA	Yan	Banghua
NOAA	Yu	Fangfang
NOAA	Zou	Cheng-Zhi
SSEC	Tobin	David
WMO	Lafeuille	Jerome

2007 Activities

- Annual Operating Plan

- Two GRWG meetings

- GDWG to discuss data management issue

- Commission GSICS Website and routine LEO to LEO intersatellite calibration, with performance reports at NESDIS

- Intercomparisons of AIRS and IASI

2008 Activities

- Commission intercalibration of MTSAT, MSG, GOES and FY2 Infrared Imagers with IASI and AIRS.

  - Routine intercomparisons between MSG (SEVIRI) and AIRS/IASI at EUMETSAT

  - Routine intercomparisons between GOES and AIRS/IASI at NESDIS

  - Routine intercomparisons between MTSAT and AIRS/IASI at JMA

  - Routine intercomparisons between FY2 and AIRS/IASI at CMA

Spectral Coverage and Example Observations of AIRS, IASI, and CrIS

MODIS & AIRS ($\Delta\nu = 2400/\nu$) Channels

AIRS, 2378

AVHRR, HIRS & IASI Channels ($\Delta\nu = 0.25$ cm^{-1})

IASI, 8461

Sampling of VIIRS & CrIS ($\Delta\nu = 0.625, 1.25, 2.50$ cm^{-1}) Channels

CrIS, 1305

Wavenumber ν, cm^{-1}
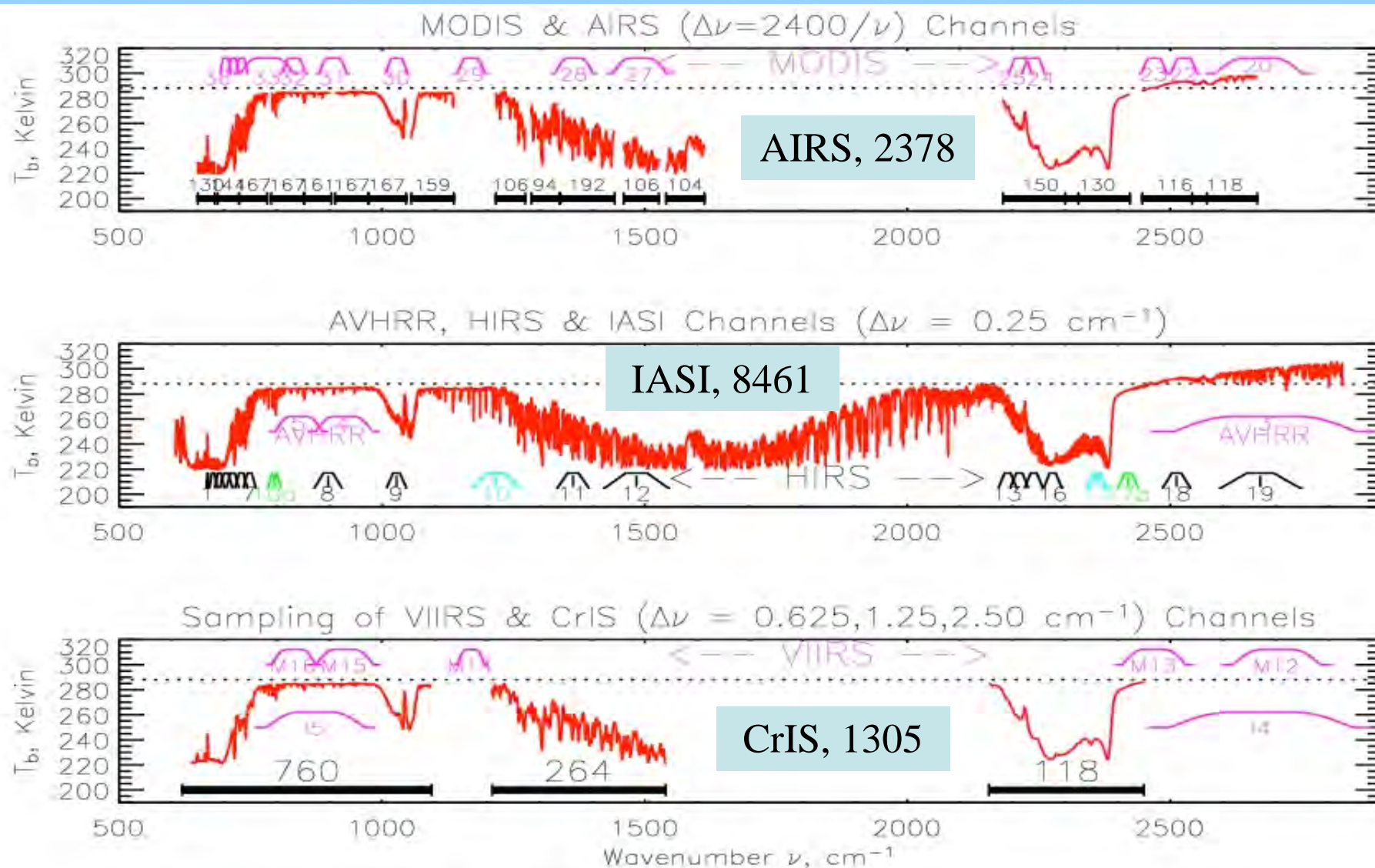
GRWG-1   (Jan 2007, NOAA)

- GRWG 1 focus on infrared measurements and address in priority:
  - Review methodologies currently applied for Geo to Leo collocations
  - Define an agreed GEO to LEO collocation methodology for IR sensors
    - collocation criteria (viewing angle, time window)
    - sampling strategy (target size and numbers, geographical coverage, target selection bright/dark clear/cloudy, temporal frequency)
    - matching technique to account for different fields of views and spectral response
    - statistical processing (bias, or regression, spectral shift, quality index)
  - Methodology for spectral convolution (comparison of IR band radiances with hyperspectral measurements)

- Expected output is:
  - Agreed initial GEO-LEO methodology,
  - Identification of software tools to be exchanged
  - Definition of a methodology to compare GEO IR radiances with AIRS and IASI radiances

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GRWG-2

- June 2007, EUMETSAT

- Main focus on intercalibration of reflective channels, noting that the co-location criteria won't be the same as for IR because of directional effects, aerosols, atmospheric backscattering, and hot spots.

- Methodology for GEO-MODIS comparison for visible channels

GDWG-1

- June 2007 EUMETSAT

  - Definition of best practices for data management

  - Definition of formats and operational procedures for data exchange

Integrated Cal/Val System Architecture

Calibration Opportunity Prediction | Data Acquisition Scheduler

Calibration Opportunity Register (CORE)

Raw Data Acquisition for Calibration Analyses

Stored Raw Data for Calibration Analyses

| SNO/ SCO Rad. Bias and Spectral Analysis | Calibration Parameter Noise/ Stability Monitoring | RTM Model Rad. at Calibration Reference Sites | Inter- sensor Bias and Spectral Analysis | Earth & Lunar Calibration | Geolocation Assessment (Coastlines, etc.) |

Assessment Reports and Calibration Updates

GSICS Outcome

- Coordinated international intersatellite calibration program

- Exchange of critical datasets for cal/val

- Best practices/requirements for monitoring observing system performance (with CEOS WGCV)

- Best practices/requirements for prelaunch characterisation (with CEOS WGCV)

- Establish requirements for cal/val (with CEOS WGCV)

- Advocate for benchmark systems

- Quarterly reports of observing system performance and recommended solutions

- Improved sensor characterisation

- High quality radiances for NWP & Climate

Technical Approach

Satellite-to-Satellite

Satellite-to-Aircraft

Satellite-to-Model

Satellite-to-Ground

Satellite to Satellite

Simultaneous Nadir Overpass (SNO) Method
-a core component in the Integrated Cal/Val System

POES intercalibration

• Useful for remote sensing scientists, climatologists, as well as calibration and instrument scientists

• Support new initiatives (GEOSS and GSICS)

• Significant progress are expected in GOES/POES intercal in the near future
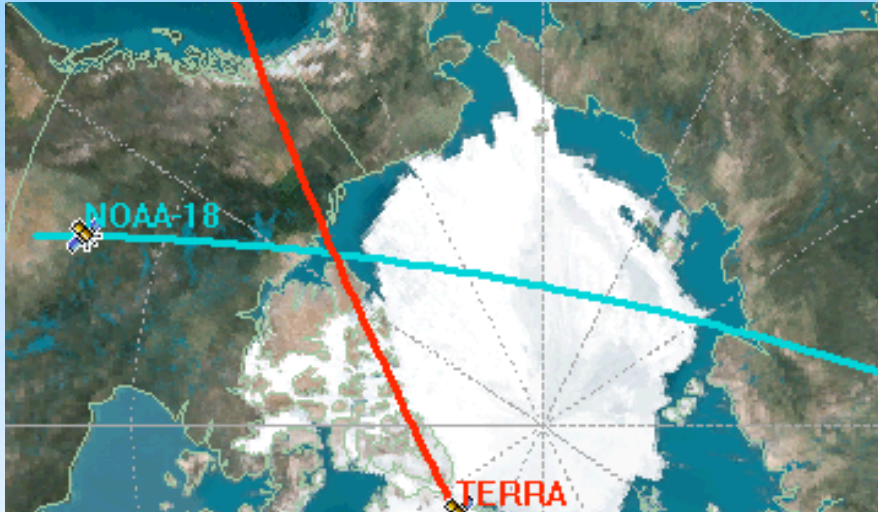
•Unique capabilities developed at NESDIS

•Has been applied to microwave, vis/nir, and infrared radiometers for on-orbit performance trending and climate calibration support

•Capabilities of 0.1 K for sounders and 1% for vis/nir have been demonstrated in pilot studies

•Method has been adopted by other agencies
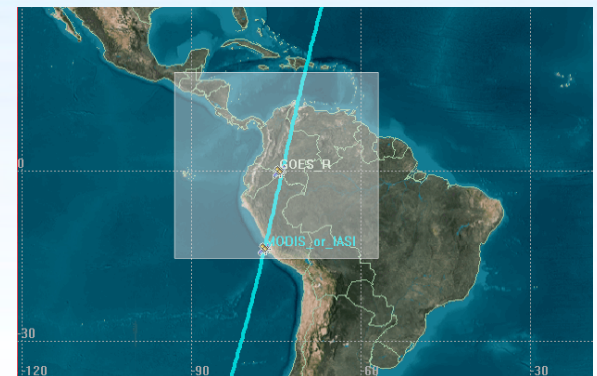
GOES vs. POES 26

SNO Applications

NOAA-12 vs NOAA-11 MSU Channel 2
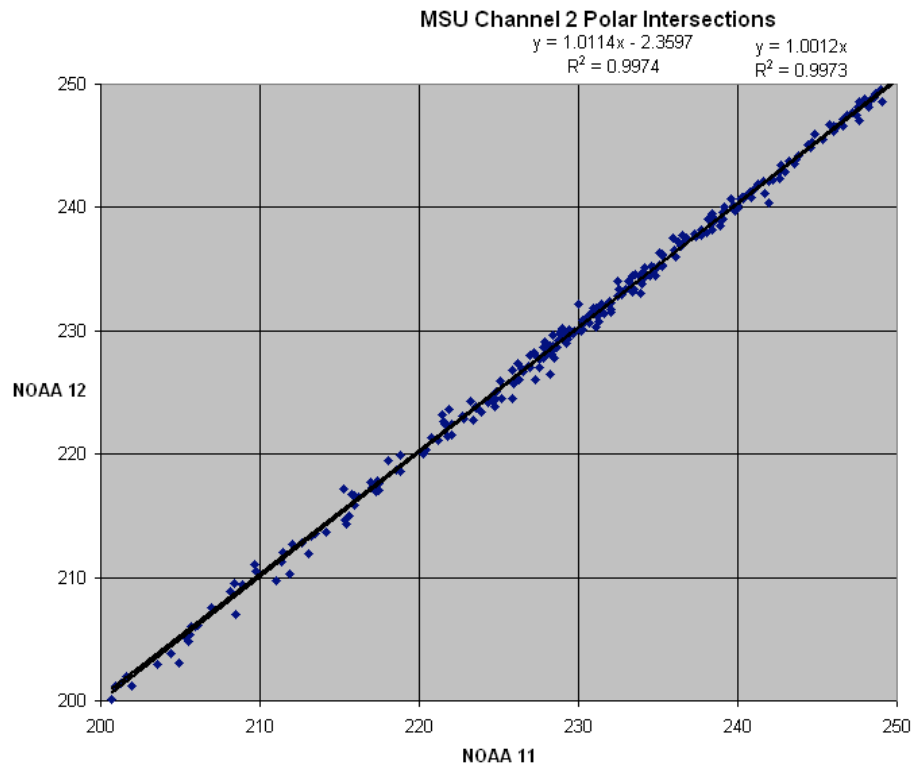
Example of one month of SNO's between TERRA/MODIS and NOAA-17 AVHRR

MSU Channel 2 Polar Intersections

$y = 1.0114x - 2.3597$
$R^2 = 0.9974$

$y = 1.0012x$
$R^2 = 0.9973$

NOAA 12

NOAA 11

MODIS 0.86 µm Reflectance

$fit = 0.00000 + 0.141508$

AVHRR Ch2 (0.86 µm) Count

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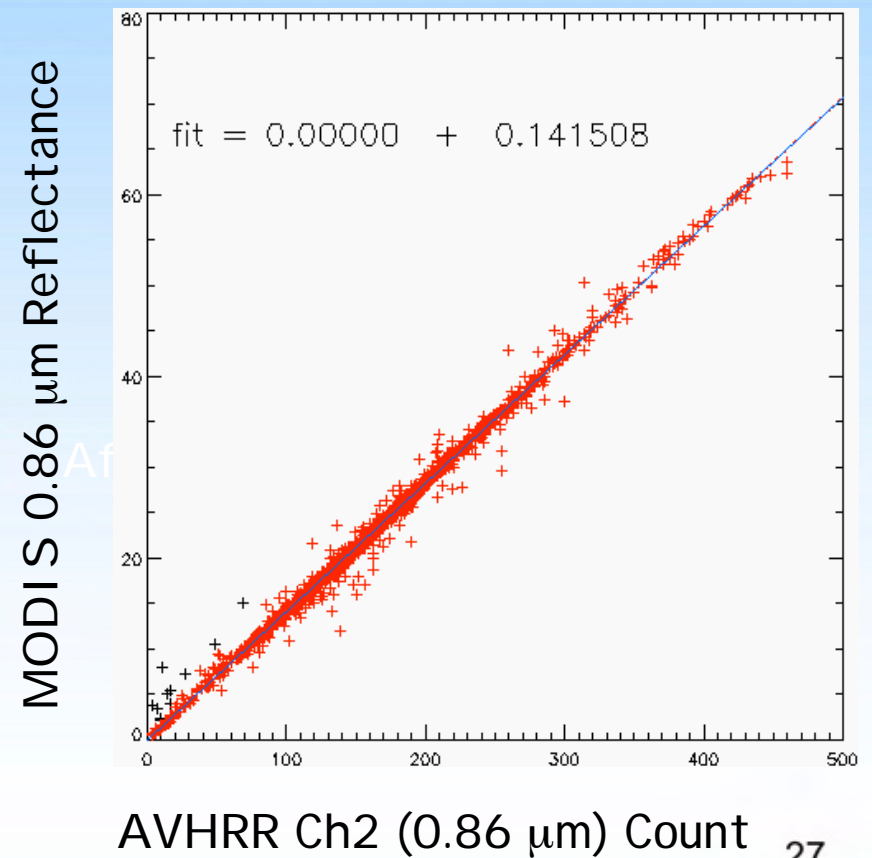
Satellite Intercalibration improves MSU time series

Simultaneous Nadir Overpass (SNO)

NESDIS Operational Calibration

Trend: N10 = - 0.40 K Dec^{-1}, N11 = 0.80 K Dec^{-1},
N12 = 0.36 K Dec^{-1}, N14 = 0.43 K Dec^{-1}

Improved Calibration

Trend: N10 = -0.39 K Dec^{-1}, N11 = 0.58 K Dec^{-1}
N12 = 0.43 K Dec^{-1}, N14 = 0.31 K Dec^{-1}
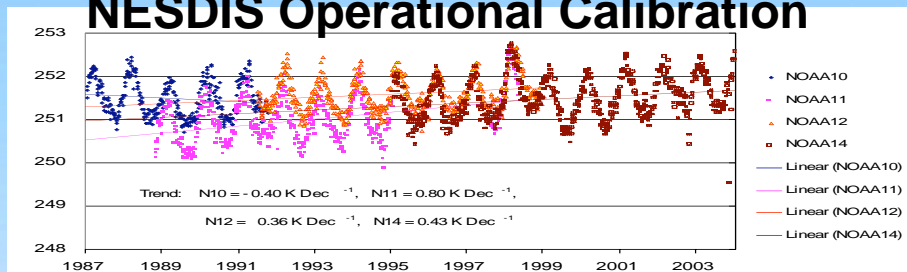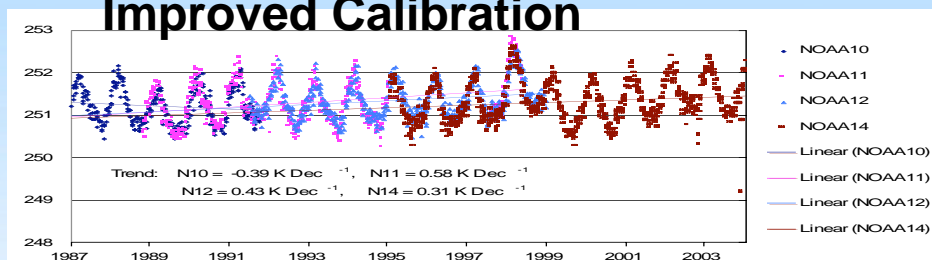
Improved calibrated radiances using SNO- improved differences between sensors by order of magnitude.

Trend = 0.17 K Dec^{-1}
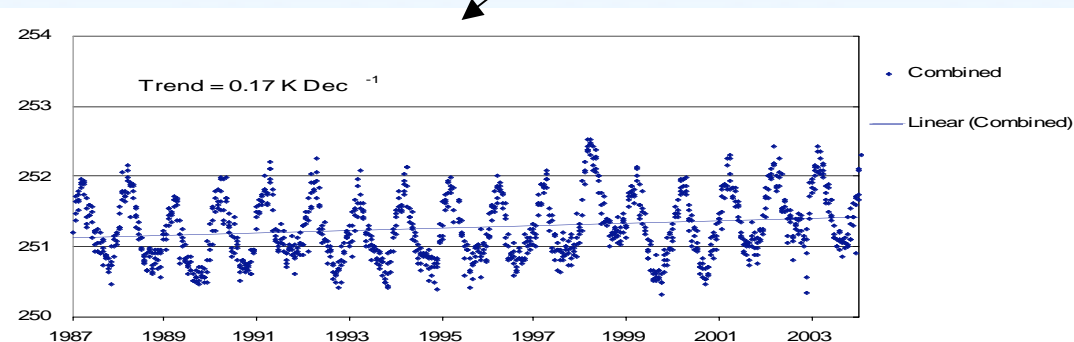
Trends for nonlinear calibration algorithm using SNO cross calibration

0.20 K Decade^{-1}

National Environmental Satellite,
Data, and Information Service

Band 3
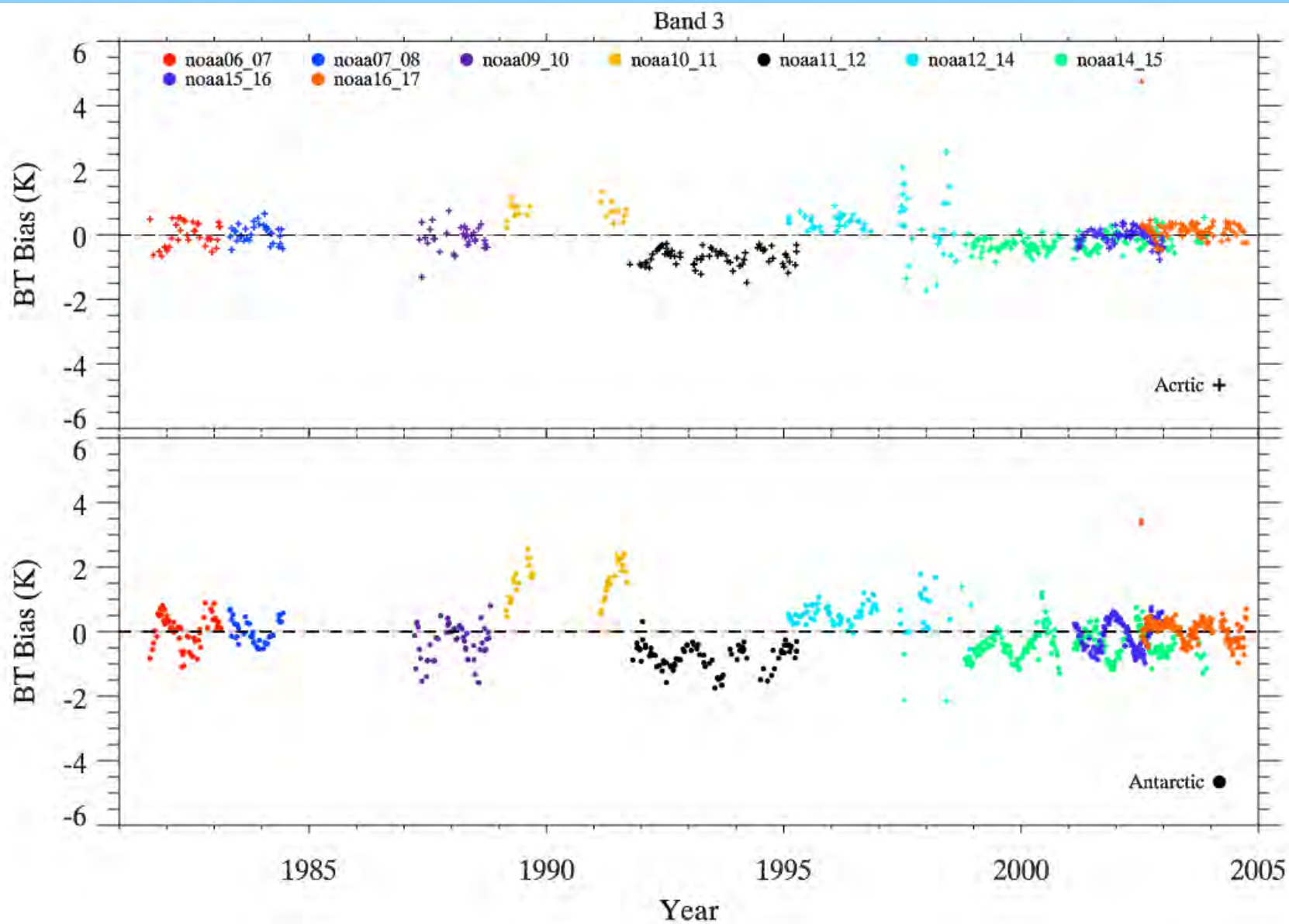
Real Data Comparison (JMA)
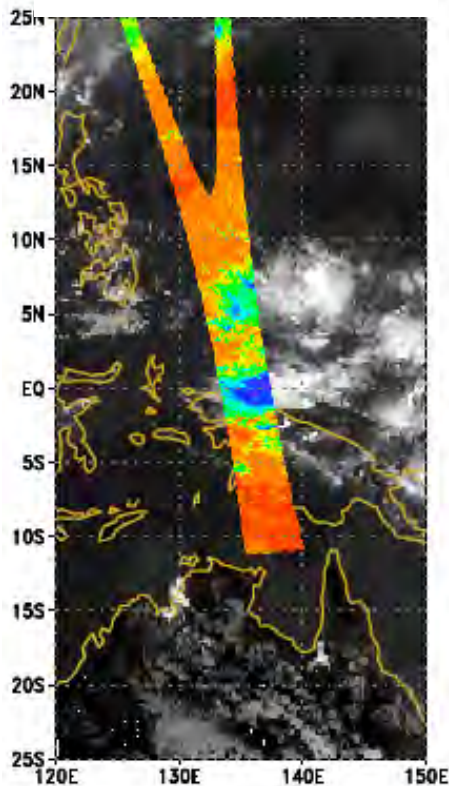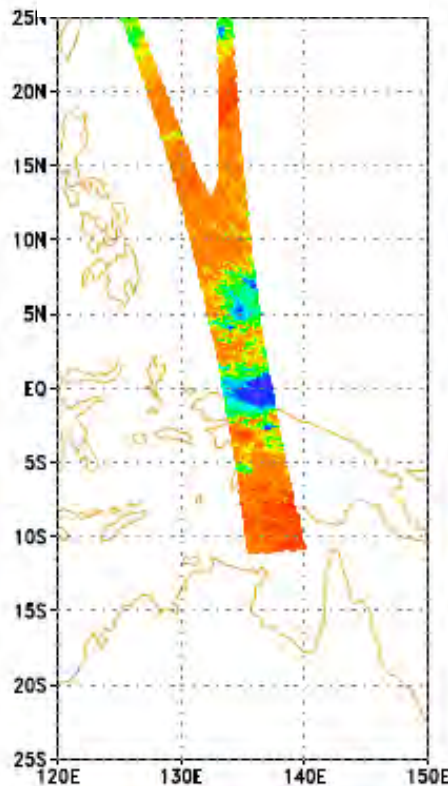
MTSAT-1R IR2 — AIRS virtual ch — MTSAT – AIRS — MTSAT – NOAA18 AVHRR ch 5
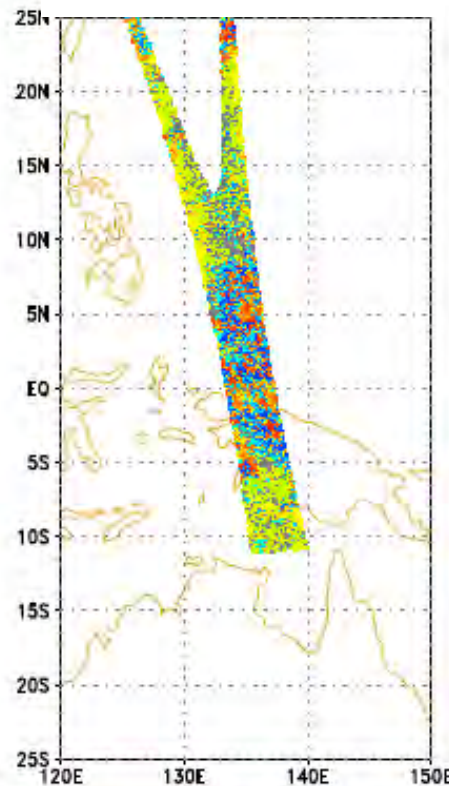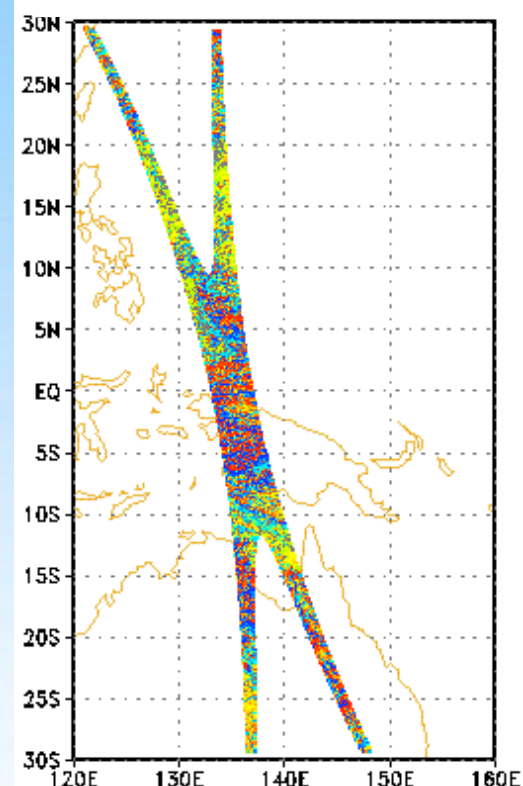
04:42 UTC, 2 Nov 2006

04:42 UTC, 3 Nov 2006

Real Data Comparison (statistics)

MTSAT-1R IR2 vs. AIRS virtual ch   MTSAT-1R vs. NOAA-18/AVHRR ch 5

MTSAT-1R IR2
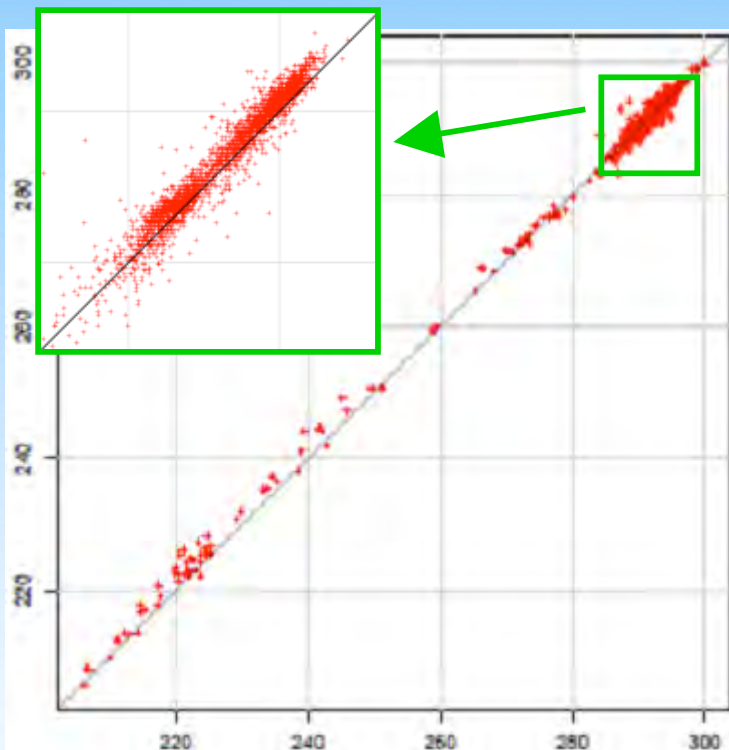
AIRS virtual ch.

Clear sky comparison

DIFF: 0.296
STDV: 0.125
NUM : 126

Smooth cloud Top comp.

DIFF: 1.795
STDV: 1.213
NUM : 249
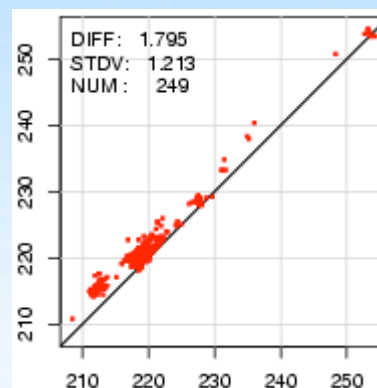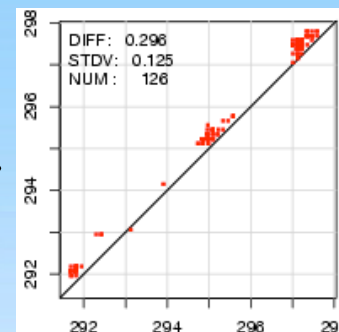
```
MEAN: +0.324 K (MTSAT-AIRS)
STDV:  0.551 K
CORR:  0.998
NUM :  3113
```

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AIRS spectrum and Aqua MODIS Band Spectral Response Functions (SSEC)

MODIS Band / wavelength(μm)
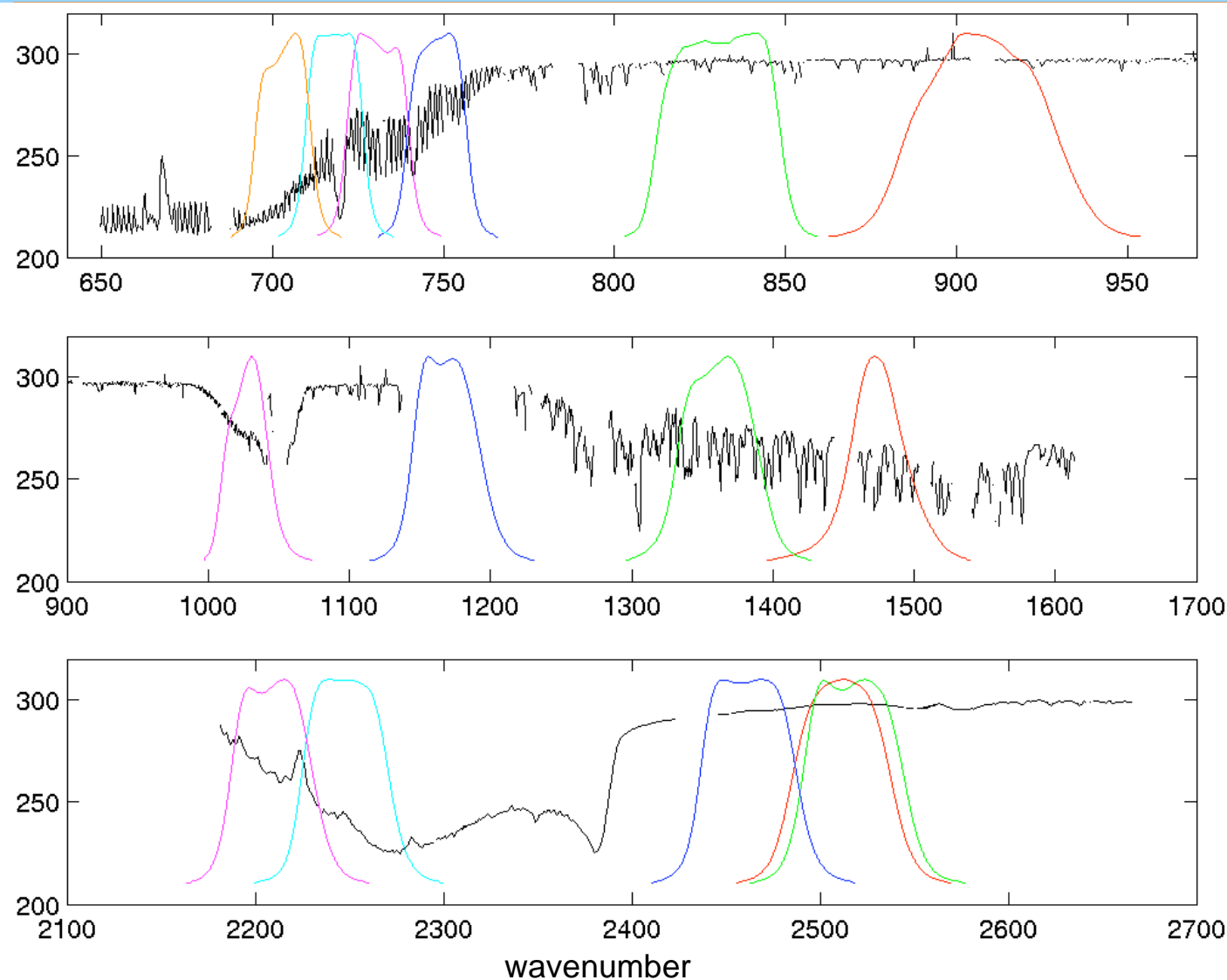
Band	/	wavelength
36	/	14.2
35	/	13.9
34	/	13.7
33	/	13.4
32	/	12.0
31	/	11.0
30	/	11.0
29	/	9.7
28	/	7.3
27	/	6.8
25	/	4.5
24	/	4.4
23	/	4.1
22	/	4.0
21	/	4.0

wavenumber

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Example comparisons for band 22 (4.0 μm) on 6 Sept 2002.
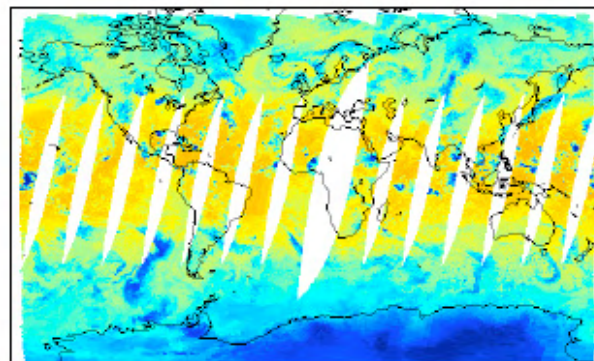
AIRS BT (K)
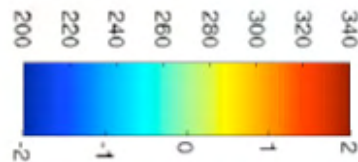
AIRS minus MODIS (K)

mean= -0.05 K
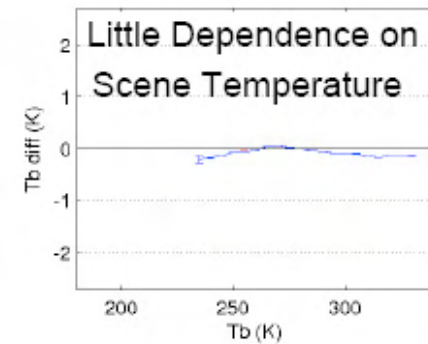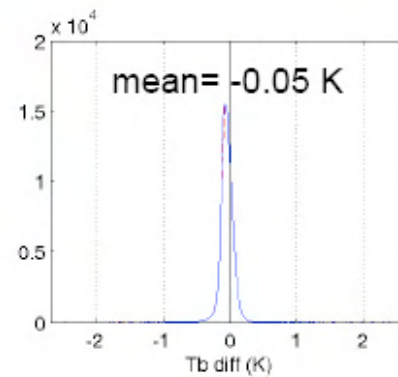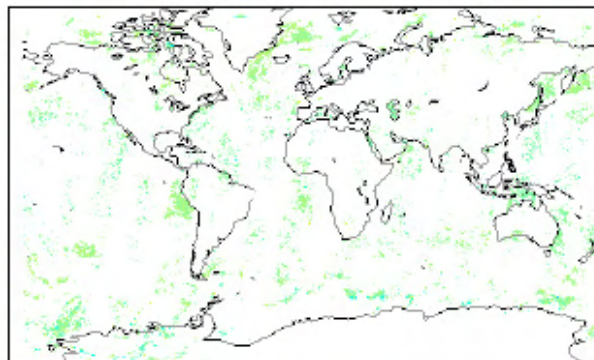
Little Dependence on Scene Temperature
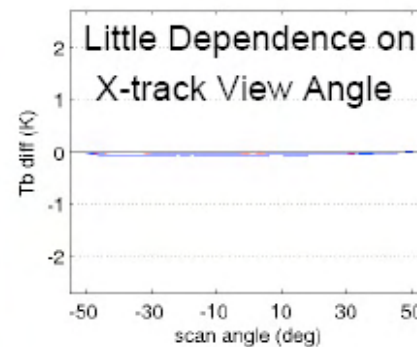
Little Dependence on X-track View Angle
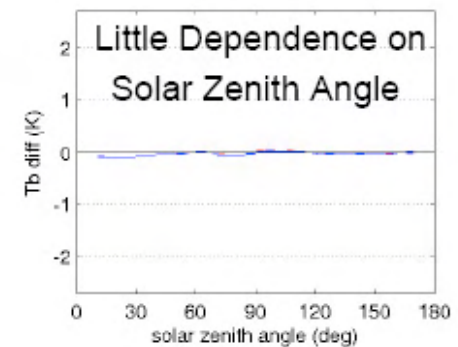
Little Dependence on Solar Zenith Angle
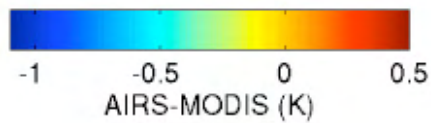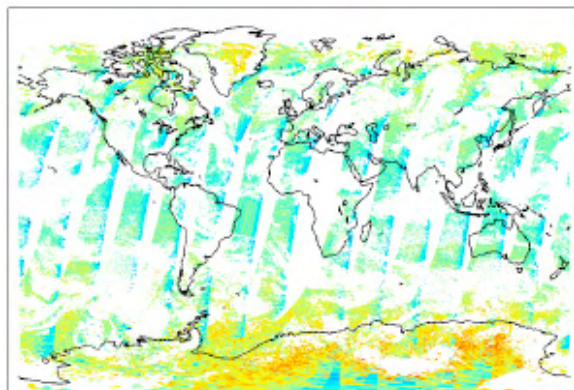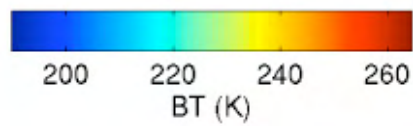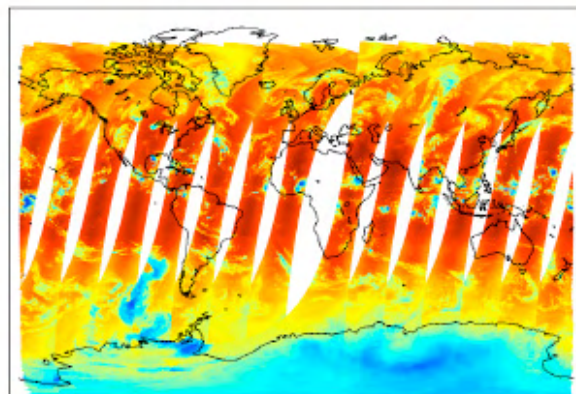
Example comparisons for band 34 (13.7 μm) on 6 Sept 2002.
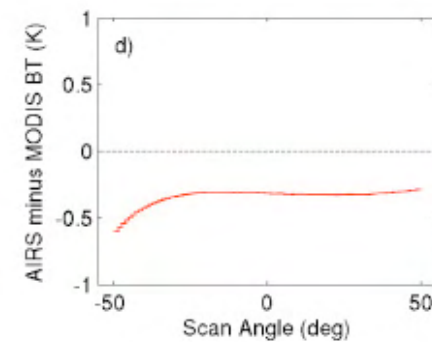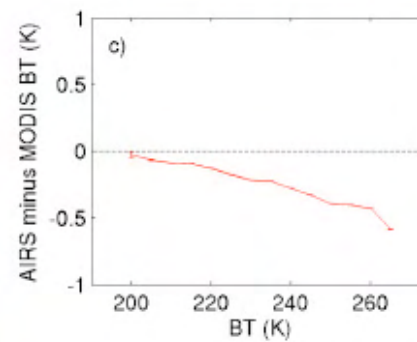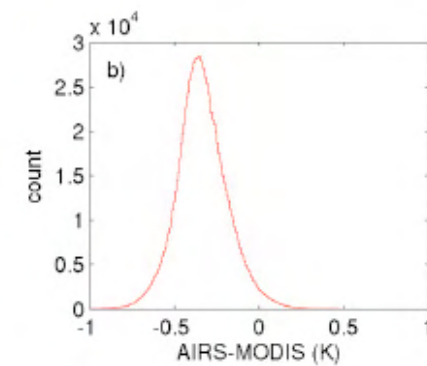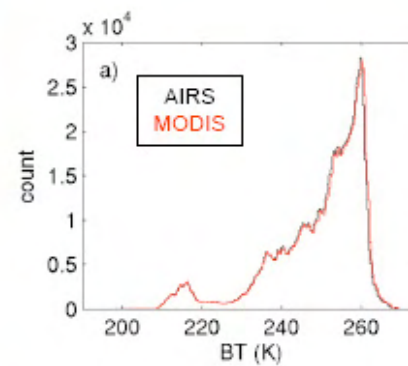
Band 35 (13.9 μm) brightness temperature differences for one orbit of data on 6 Sept 2002 using (1) the nominal MODIS SRF and (2) the MODIS SRF shifted by +0.8 cm⁻¹.
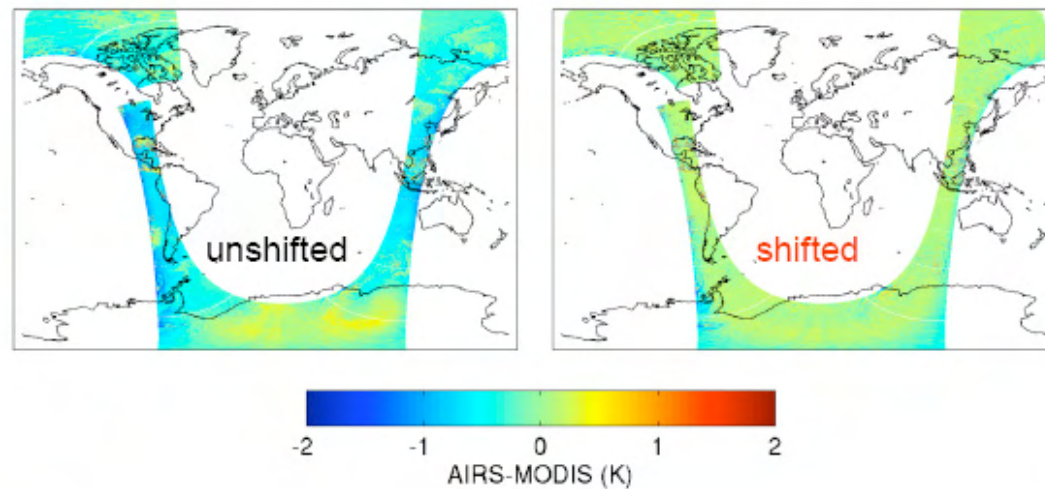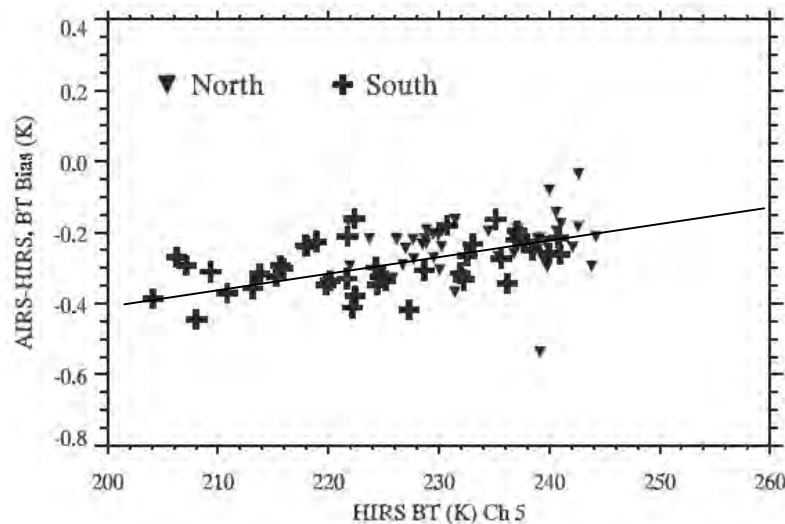
MODIS SRF out-of-band response also currently being investigated.
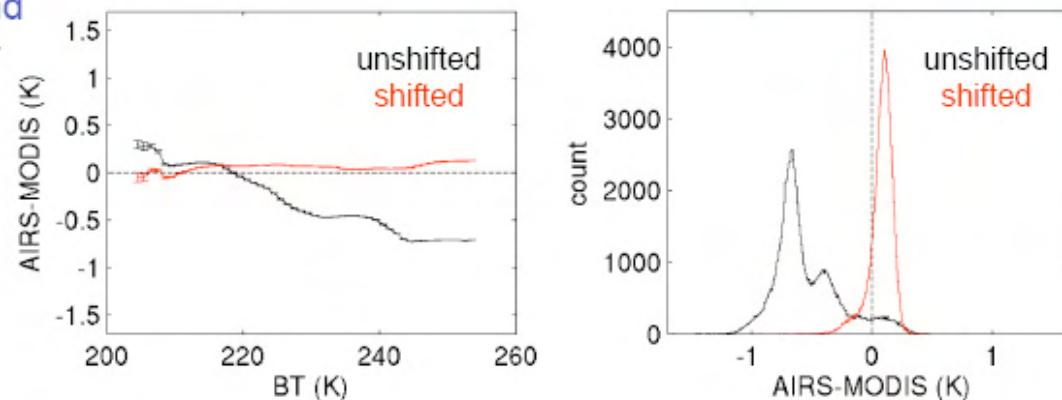
SRF Shift for HIRS Channel 6
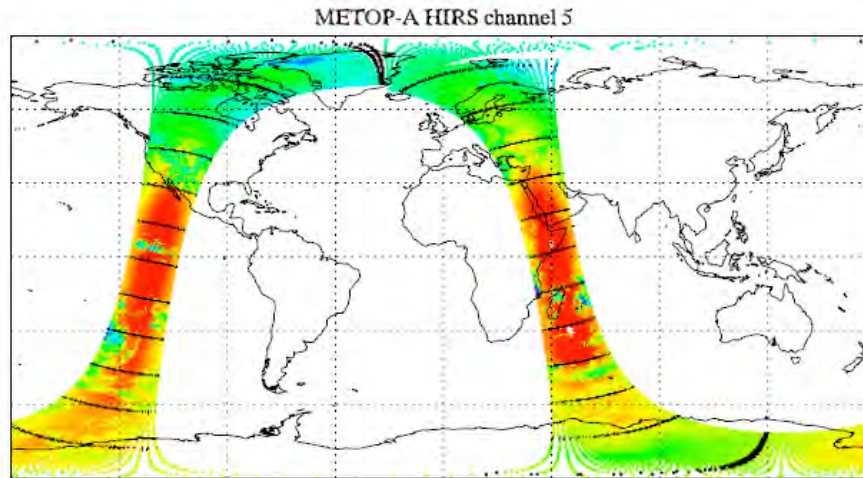
Without SRF shift

With SRF shift 0.2 cm-1
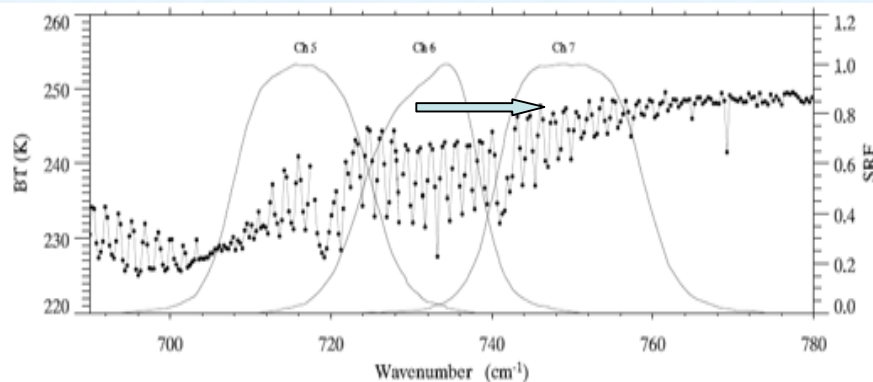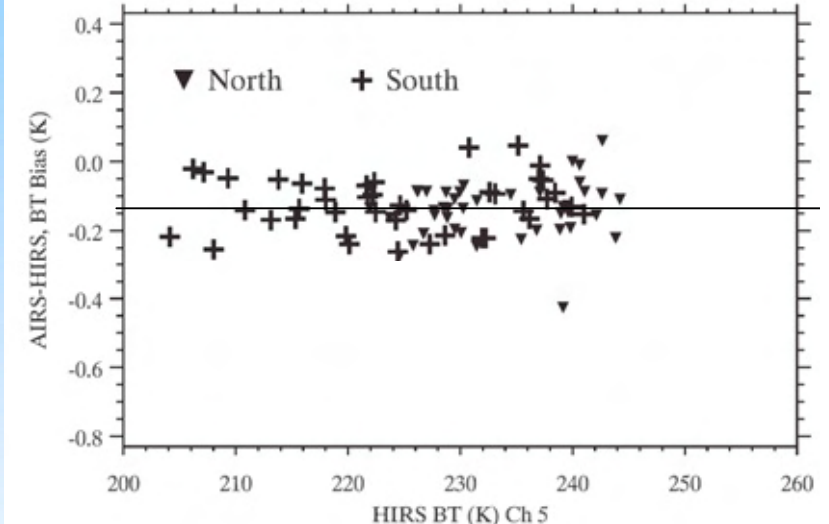
Since the HIRS sounding channels
are located at the slope region of
the atmospheric spectra, a small
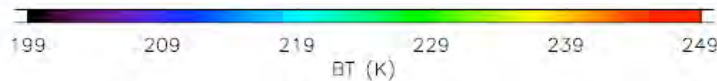shift of the SRF can cause biases in
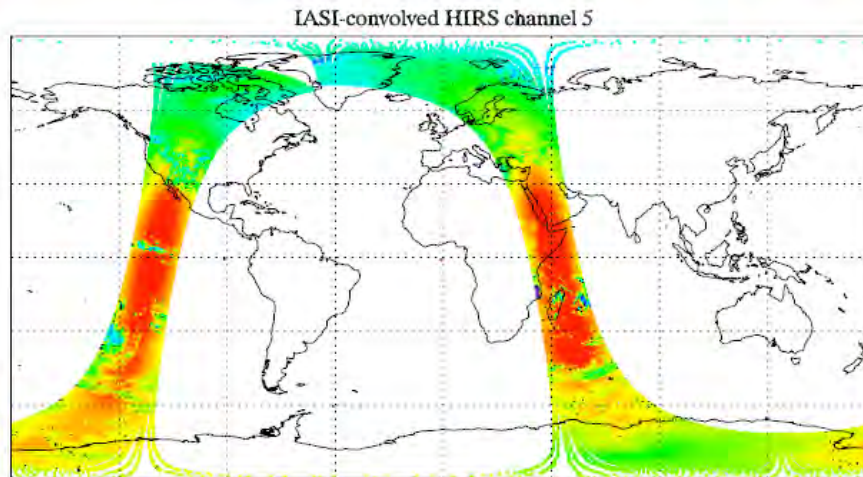observed radiances.

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Details can be referred to Wang et al. (manuscript for JTECH, 2006)

IASI-convolved HIRS vs. HIRS Ch 5

HIRS

METOP-A HIRS channel 5

IASI

IASI-convolved HIRS channel 5
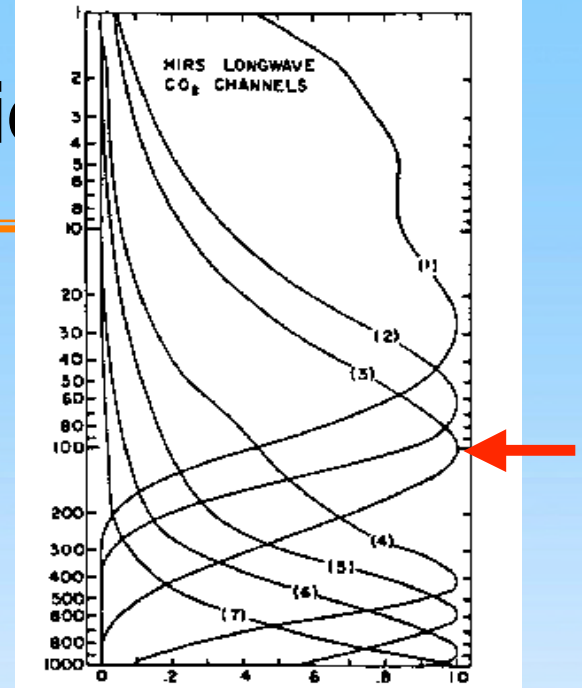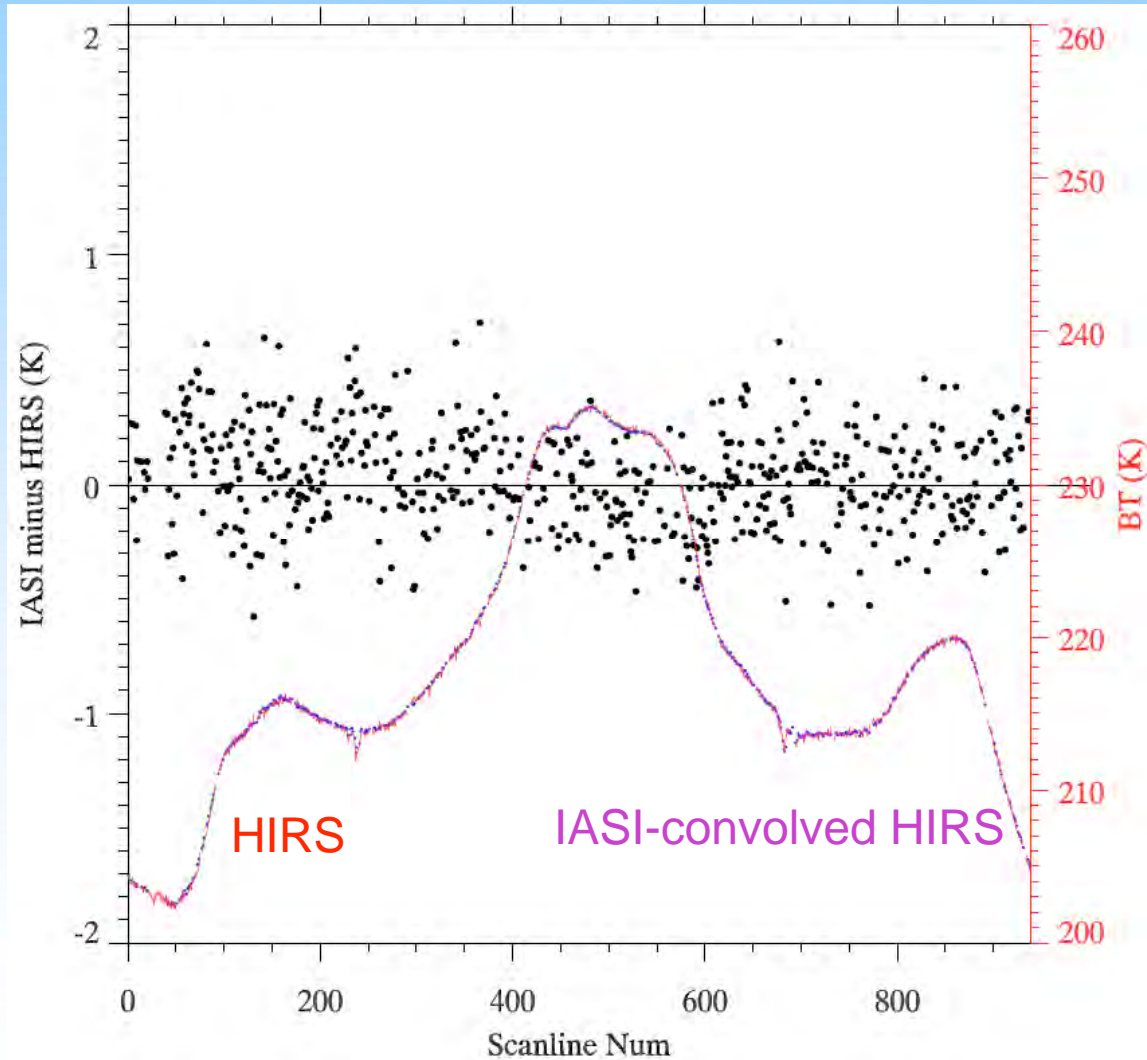
199   209   219   229   239   249
BT (K)

Brightness distribution patterns agree each other well.
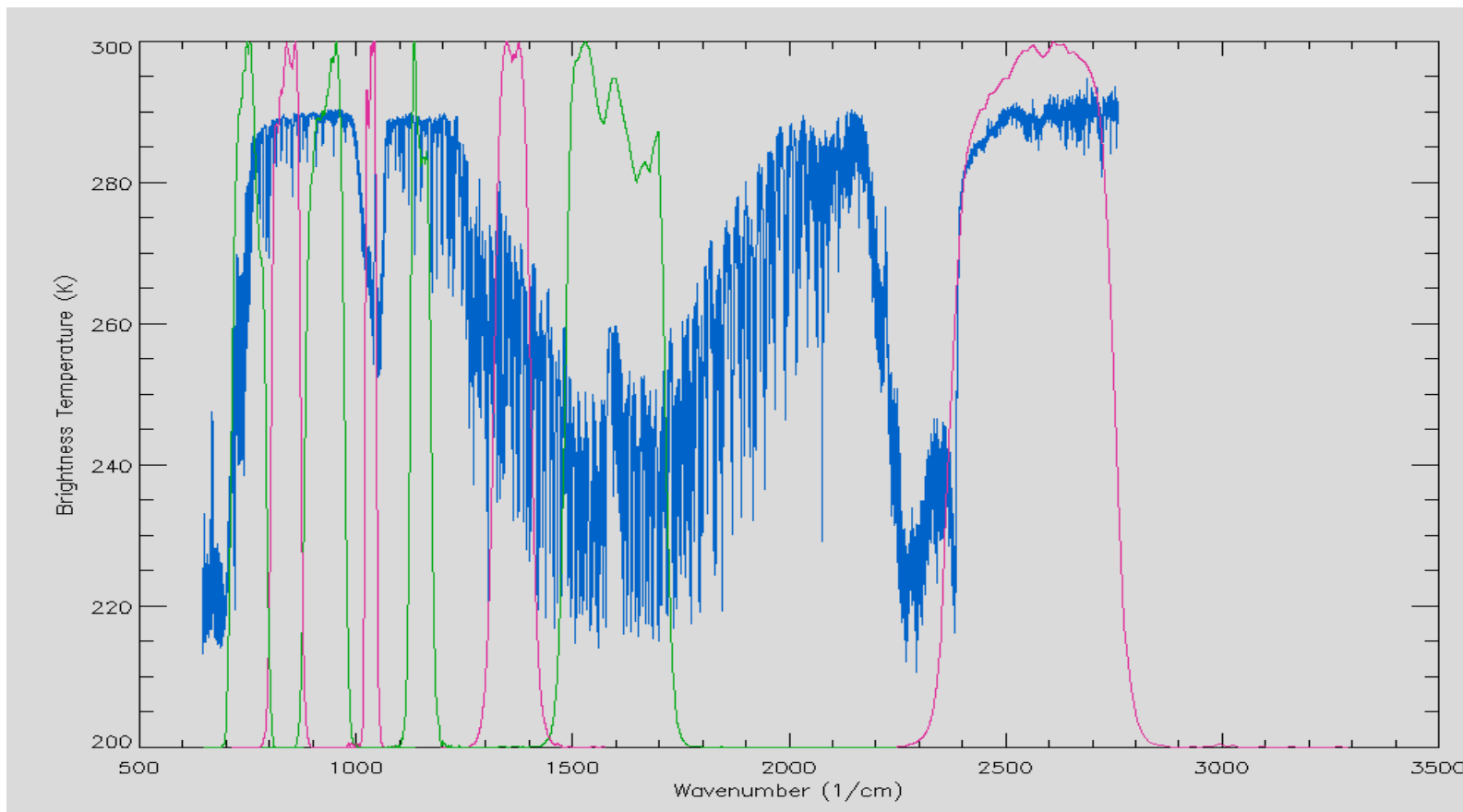
But we need the pixel-by-pixel comparison results!

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HISTOGRAM

Mean: 0.003 K
STD : 0.217 K

HIRS

IASI-convolved HIRS
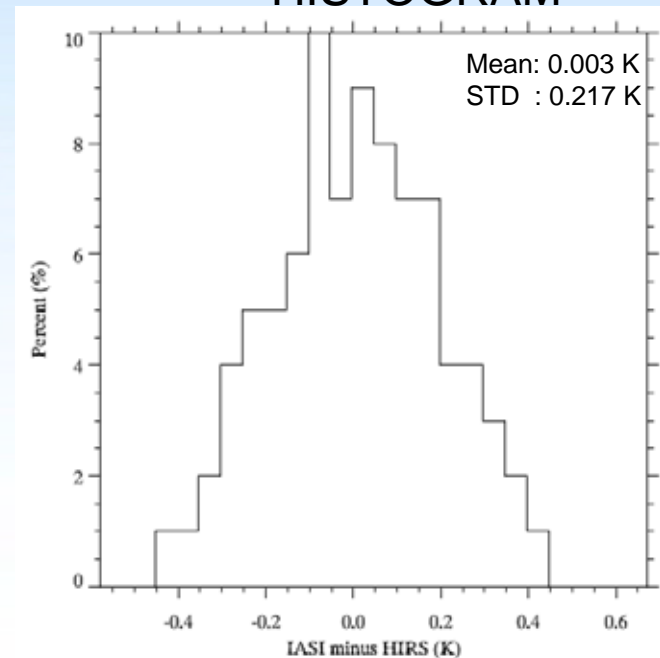
IASI Spectrum – MSG Filter

"Homogeneous" Targets (WV6.2)
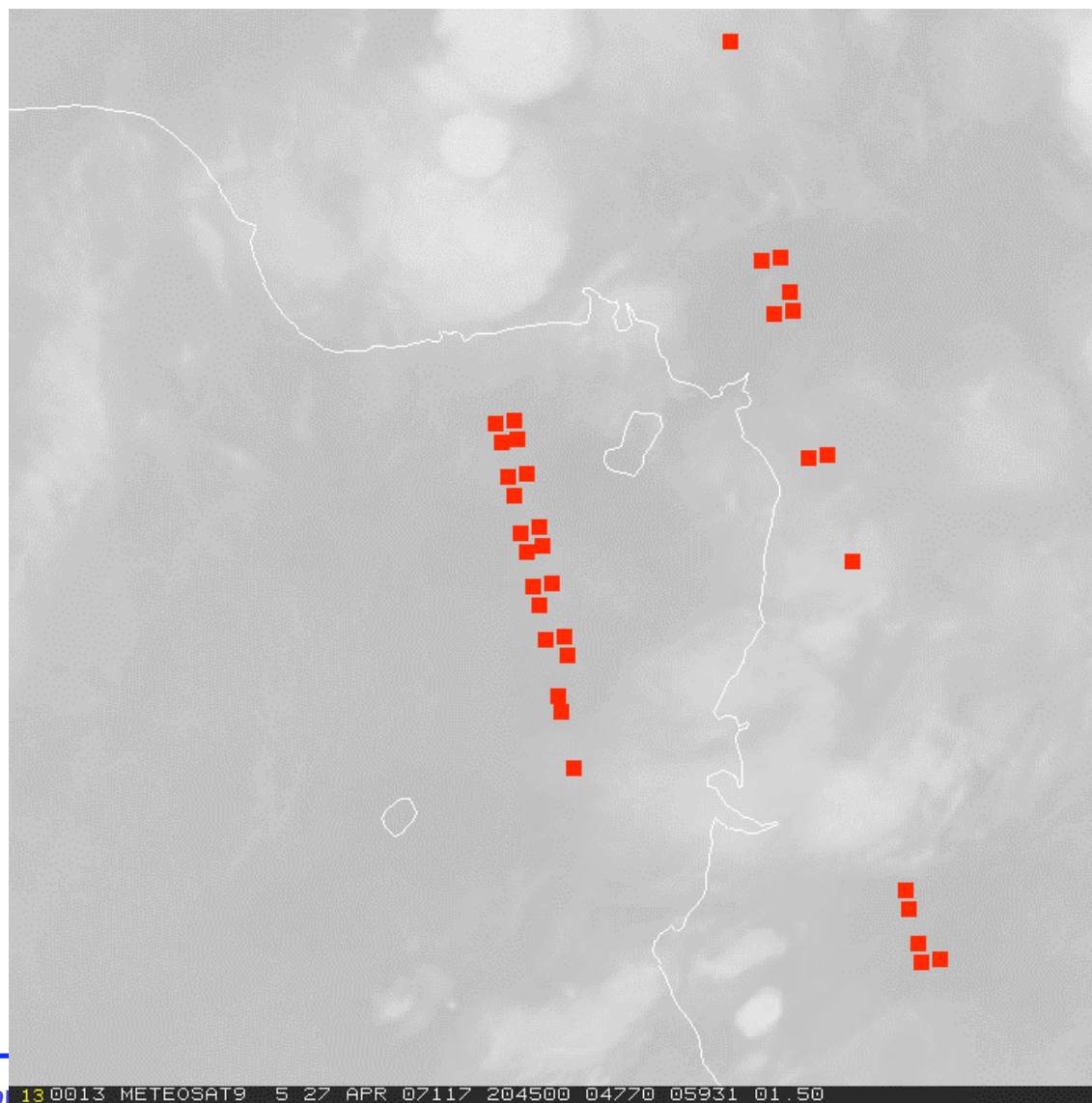
Meteosat-8
and
Meteosat-9

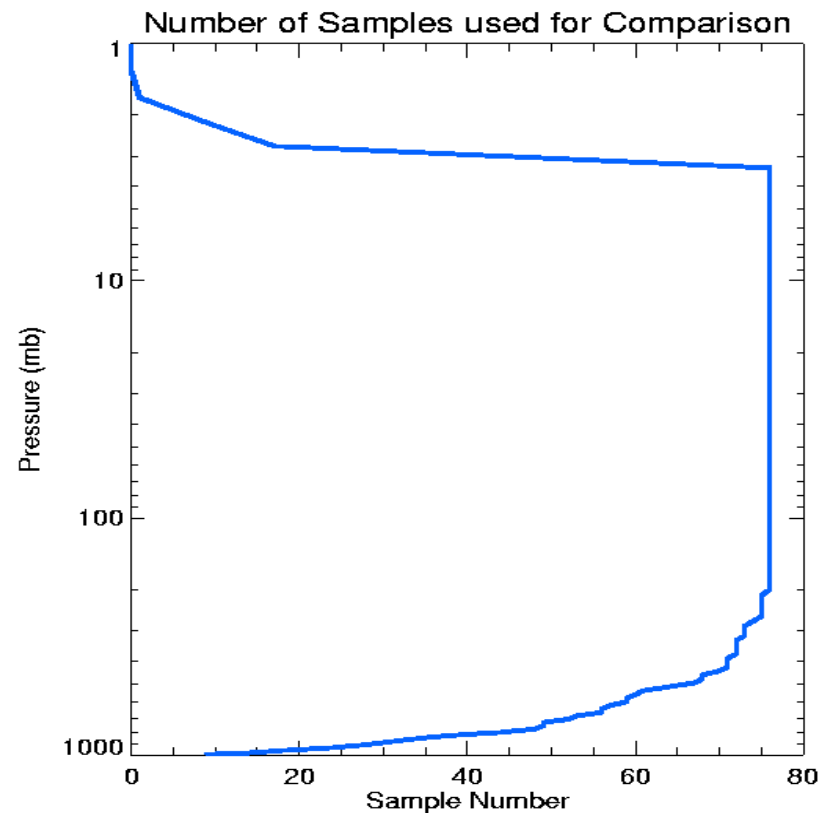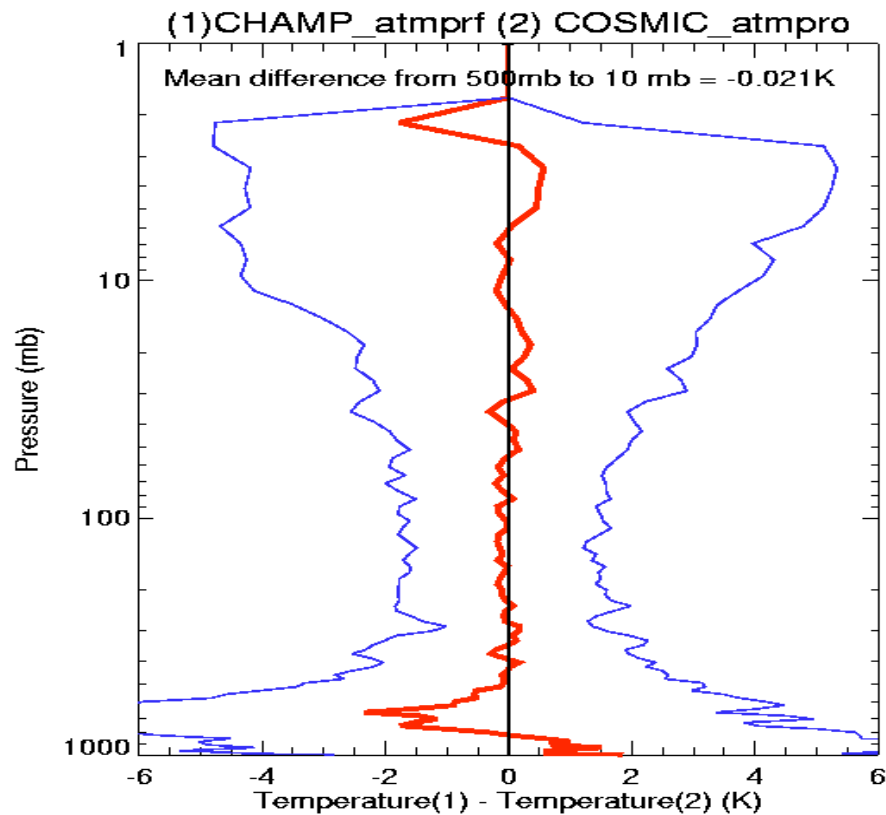| Channel	ΔT IASI – Meteosat-8*	ΔT IASI – Meteosat-9 *
IR3.9	-0.17	-0.20
WV6.2	-0.24	-0.40
WV7.3	-0.51	-0.14
IR8.7	0.15	0.15
IR9.7	0.17	0.20
IR10.8	0.16	0.07
IR12.0	0.19	0.08
IR13.4	0.44	1.7

*Uncertainty 0.1 – 0.2 K

EUMETSAT
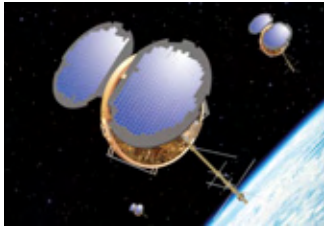
Difficulty II: to find measurements with long term stability
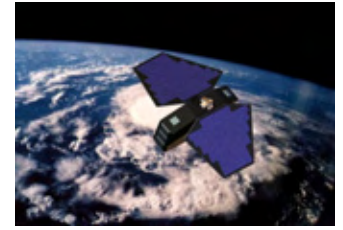
Mean bias CHAMP-COSMIC temp from 500mb to 5 mb =-0.021K

(1)CHAMP_atmprf (2) COSMIC_atmpro

Mean difference from 500mb to 10 mb = -0.021K

Number of Samples used for Comparison

COSMIC (launched in 2006) vs. CHAMP (launched in 2000) atm tmp

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Shu-peng Ben Ho, UCAR/COSMIC

Can we use GPS RO data to calibrate other instruments ?
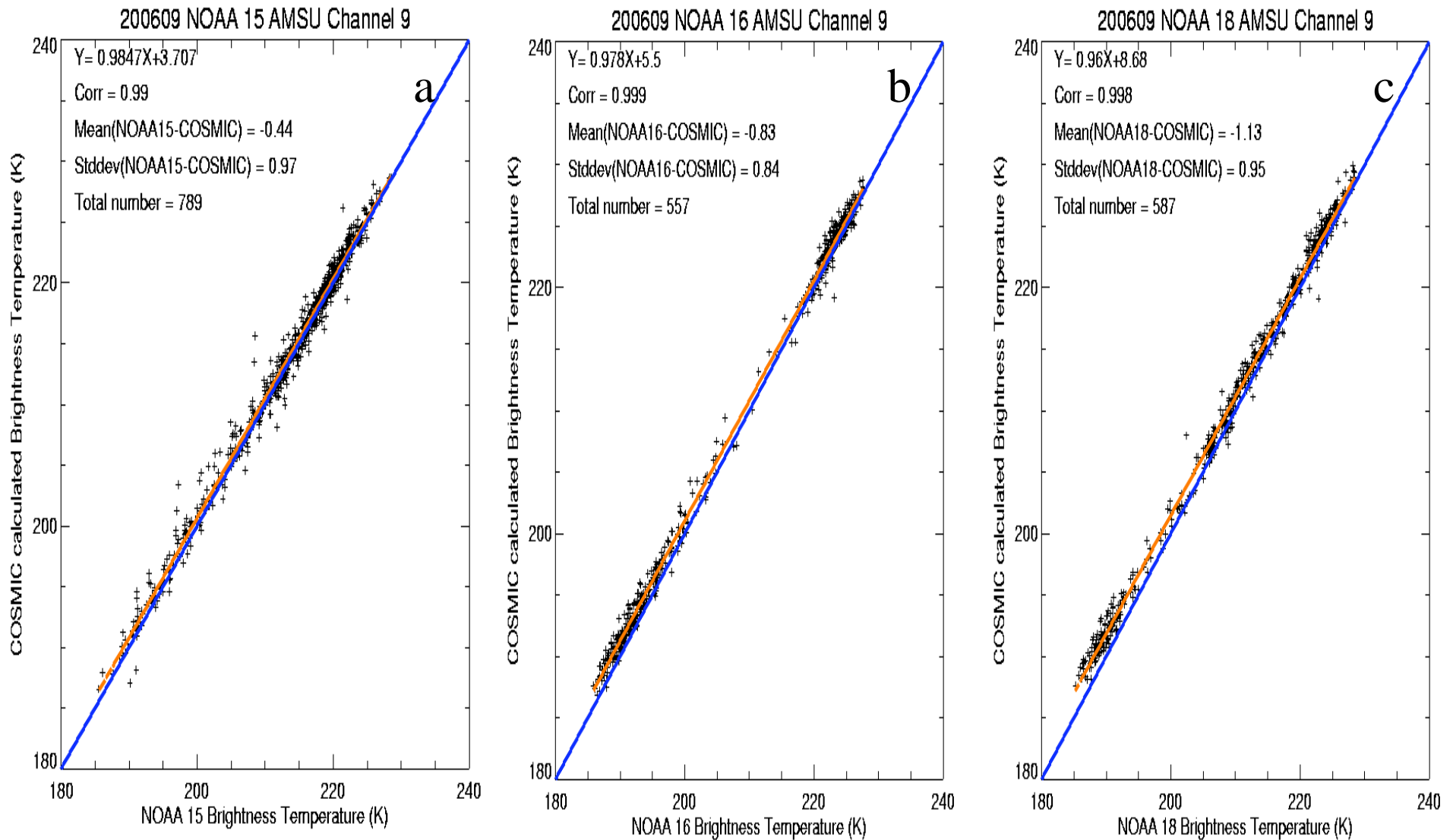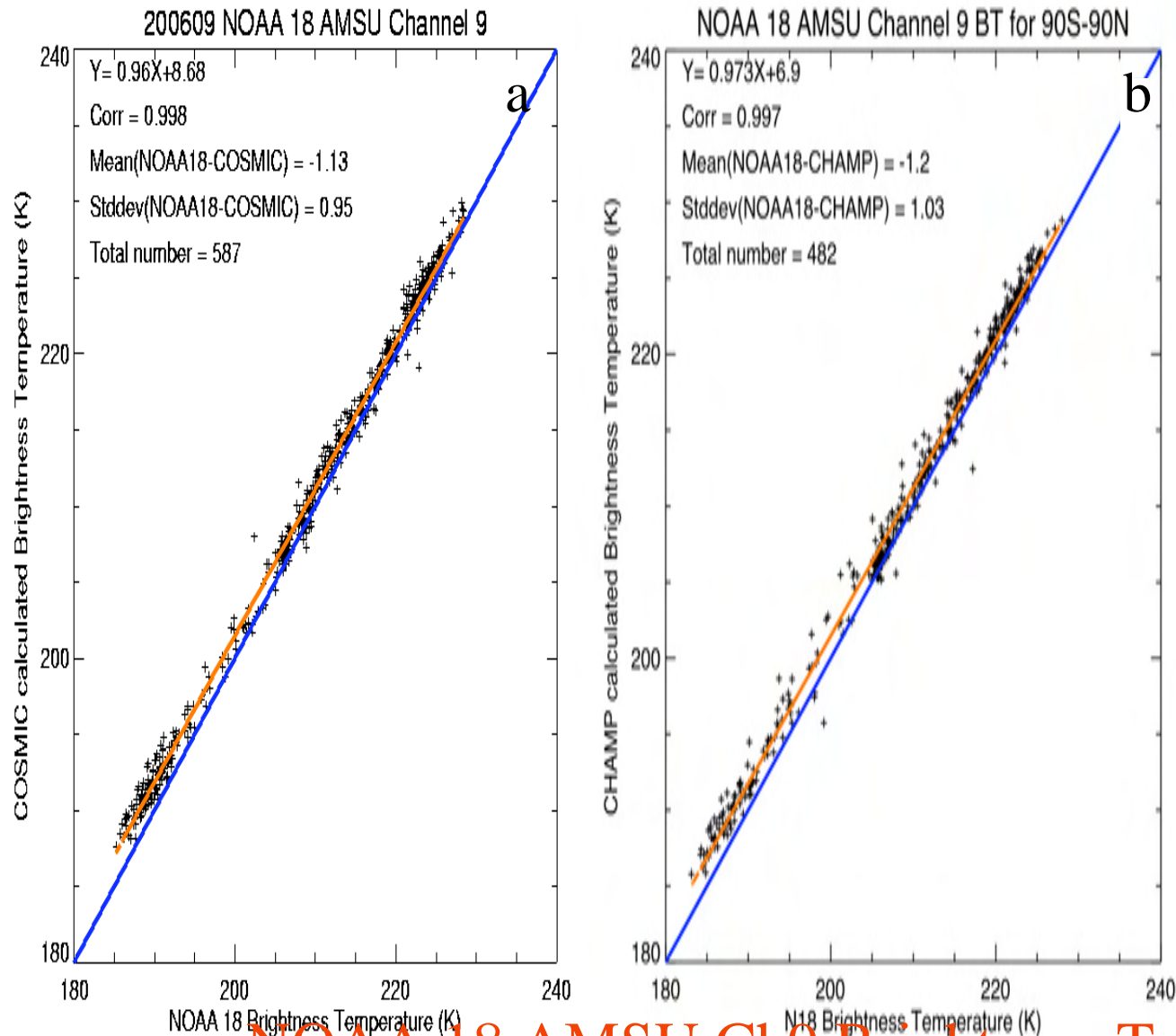

N15, N16 and N18 AMSU calibration against COSMIC

Slide 18   (Ho et al., TAO, 2007)   *Shu-peng Ben Ho, UCAR/COSMIC*

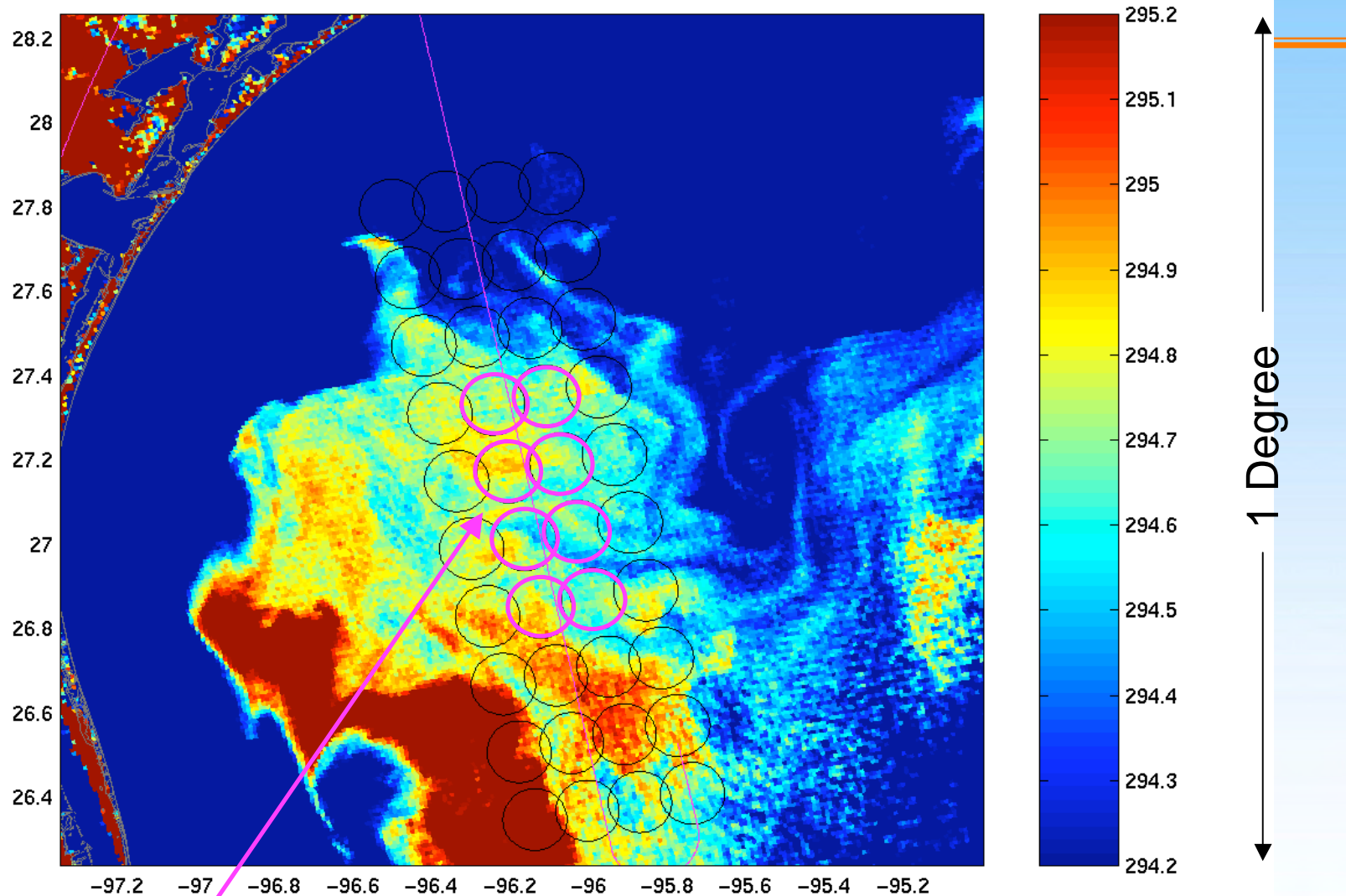# The precision of using GPS RO data to inter-calibrate other satellite is about 0.07 K

NOAA 18 AMSU Ch9 Brightness Temperature

(Ho et al., TAO, 2007)

Shu-peng Ben Ho, UCAR/COSMIC

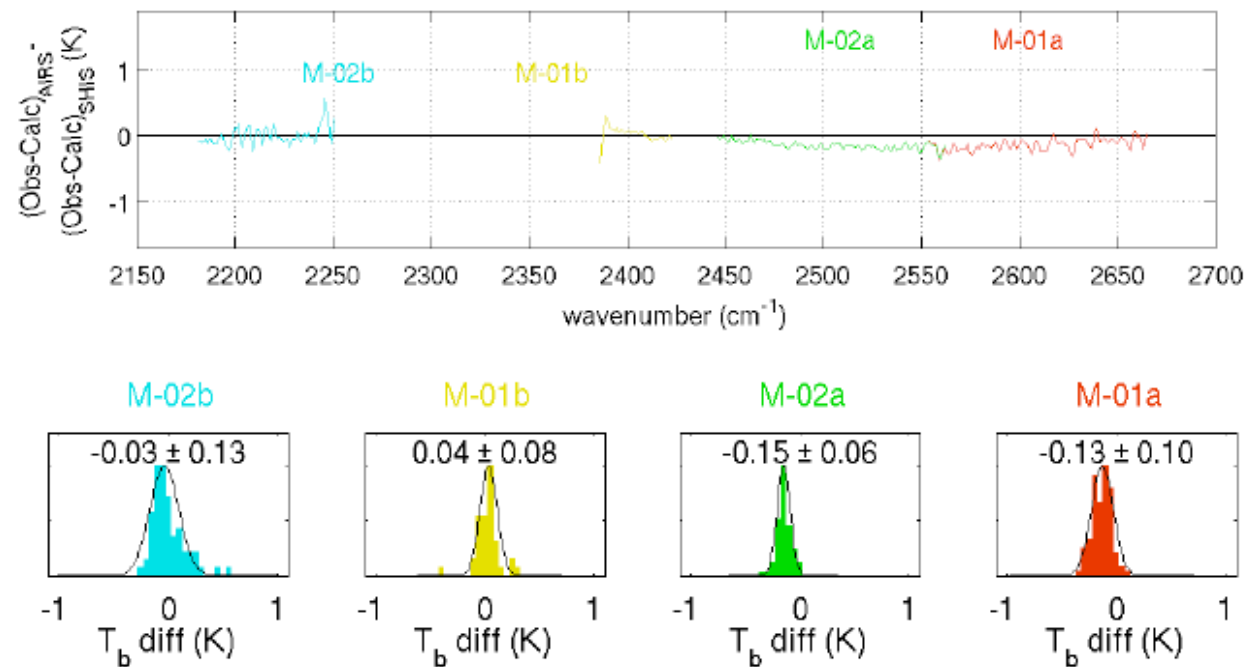# Satellite to Aircraft
(SSEC/Tobin)

Use of aircraft interferometers to validate AIRS

8 AIRS FOVs and SHIS Data w/in them (448 fovs) used in the following comparisons
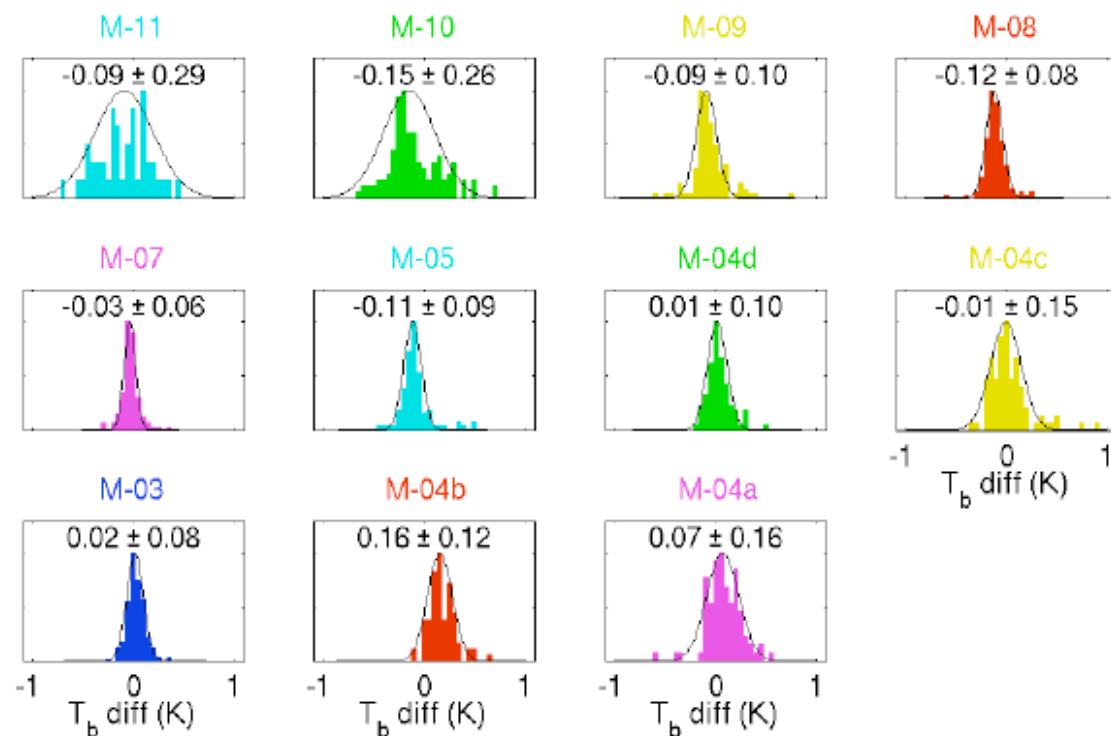
Night-time case summary: Shortwave

1st Direct SW Radiance Validation
Excellent agreement for night-time comparison
from Adriex/Italy campaign

Gulf of Mexico Validation case: 2002.11.21

Satellite to Model

Understanding Global Biases and Developing Calibration Algorithms for Bias Correction

SSMIS (54.4 GHz)
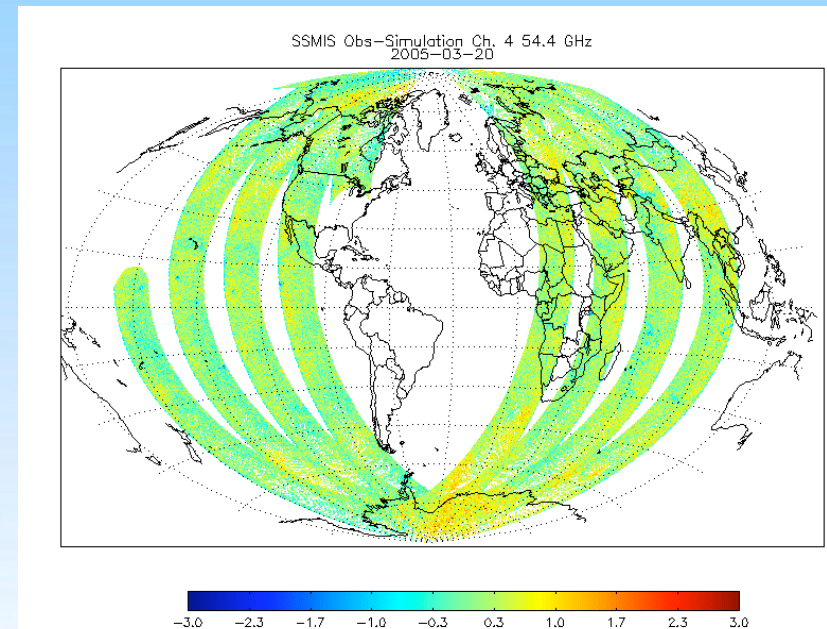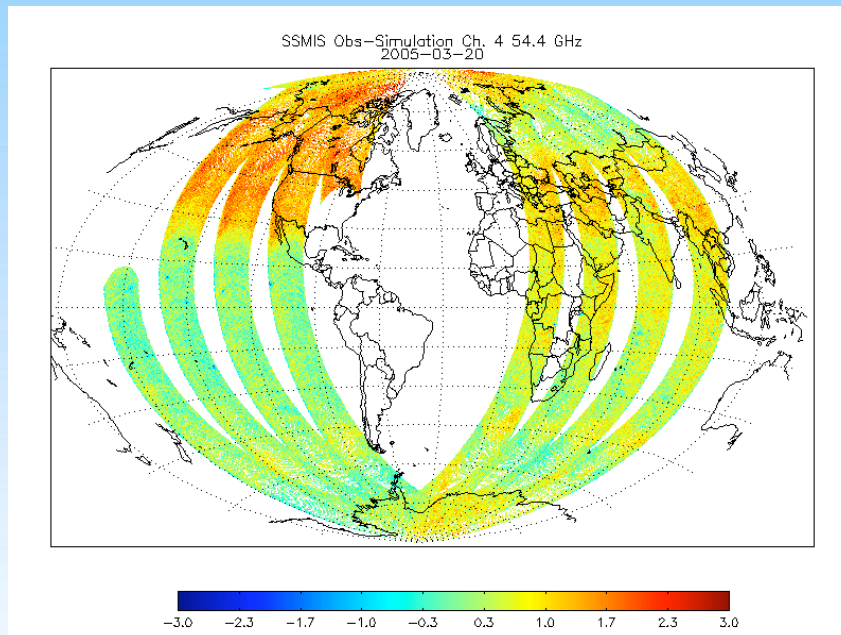
- **SSMIS is the first conical microwave sounding instrument, precursor of NPOESS CMIS.**
- **Shown are the differences between observed and simulated measurements.**
  Biases are caused by 1) antenna emission, 2) direct solar heating to warm load and 3) stray light contamination to its calibration targets.

Satellite to Ground

AVHRR VIS/NIR Vicarious Calibration using the Libyan Desert Target

NOAA 16 AVHRR Albedo
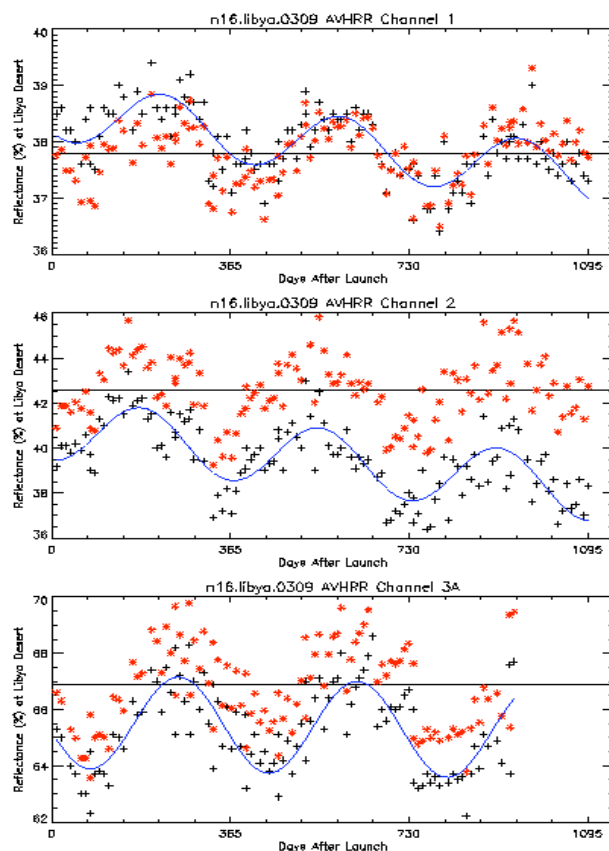
CH1

CH2

CH3

NOAA 17 AVHRR Albedo

Courtesy of X. Wu

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Simultaneous Nadir Overpass(SNO) Observation System - Mozilla

File   Edit   View   Go   Bookmarks   Tools   Window   Help

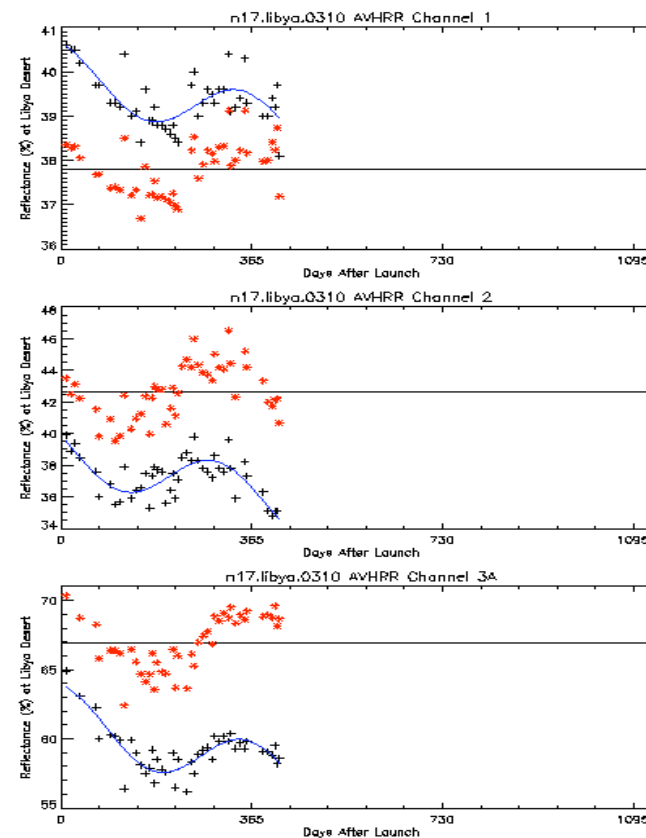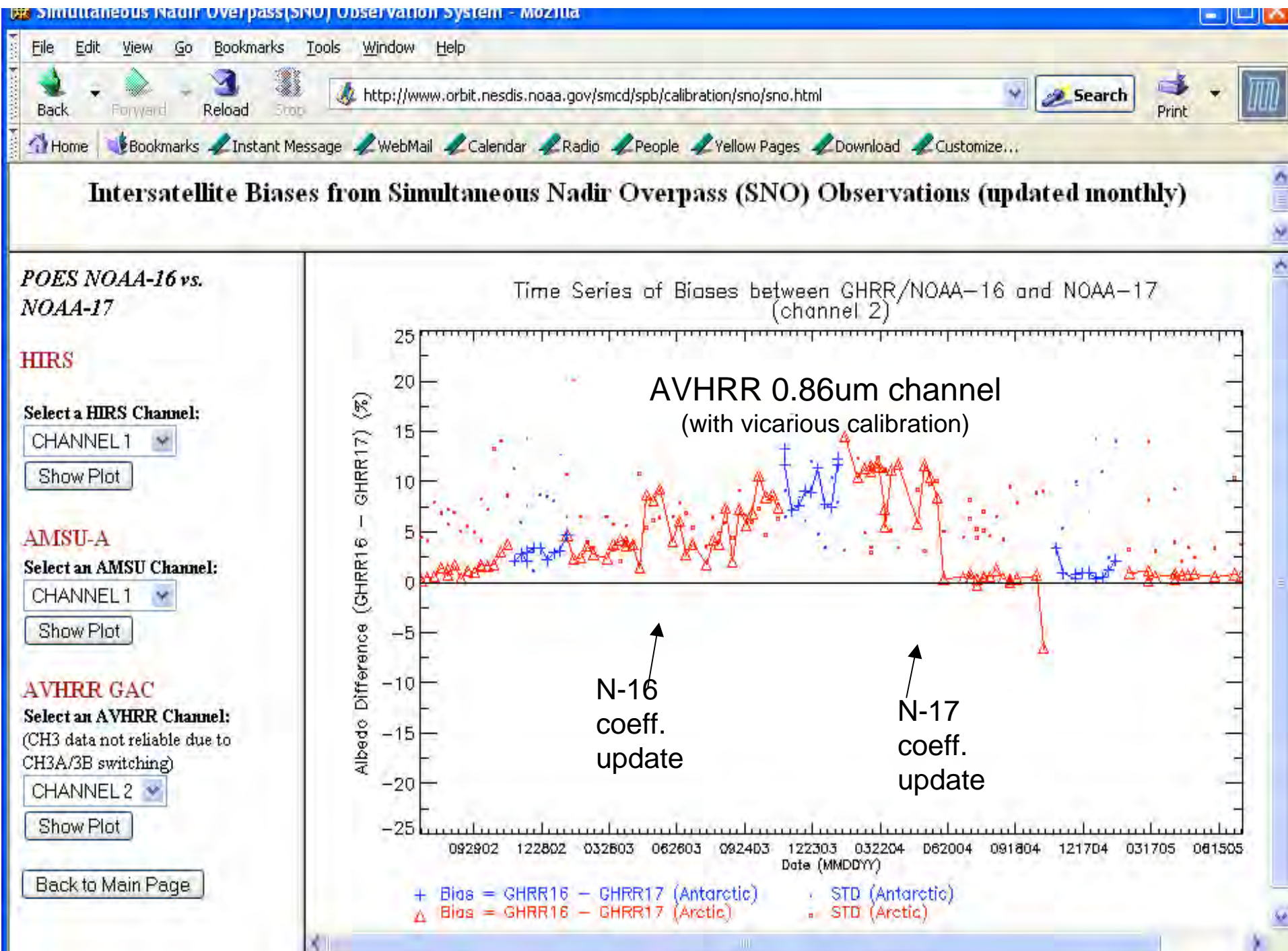Back   Forward   Reload   Stop   http://www.orbit.nesdis.noaa.gov/smcd/spb/calibration/sno/sno.html   Search   Print

Home   Bookmarks   Instant Message   WebMail   Calendar   Radio   People   Yellow Pages   Download   Customize...

Intersatellite Biases from Simultaneous Nadir Overpass (SNO) Observations (updated monthly)

POES NOAA-16 vs. NOAA-17

HIRS

Select a HIRS Channel:

CHANNEL 1

Show Plot

AMSU-A

Select an AMSU Channel:

CHANNEL 1

Show Plot

AVHRR GAC

Select an AVHRR Channel:
(CH3 data not reliable due to CH3A/3B switching)

CHANNEL 2

Show Plot

Back to Main Page

Time Series of Biases between GHRR/NOAA−16 and NOAA−17 (channel 2)

AVHRR 0.86um channel
(with vicarious calibration)

N-16 coeff. update

N-17 coeff. update

+ Bias = GHRR16 − GHRR17 (Antarctic)   STD (Antarctic)
△ Bias = GHRR16 − GHRR17 (Arctic)   STD (Arctic)

Use of DOE ARM TWP reference sites to improve radiative transfer
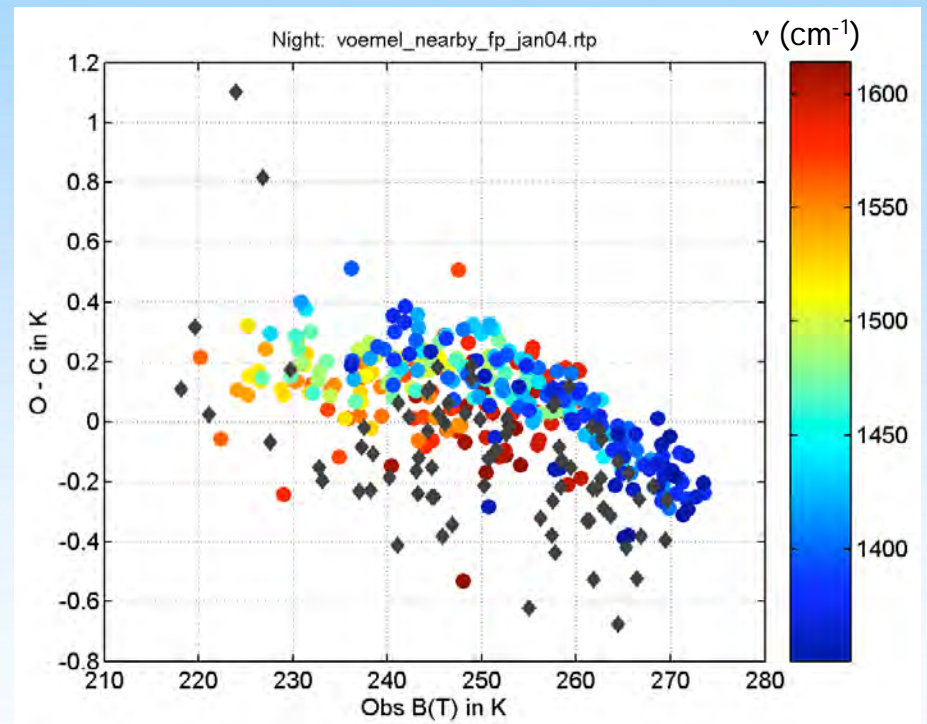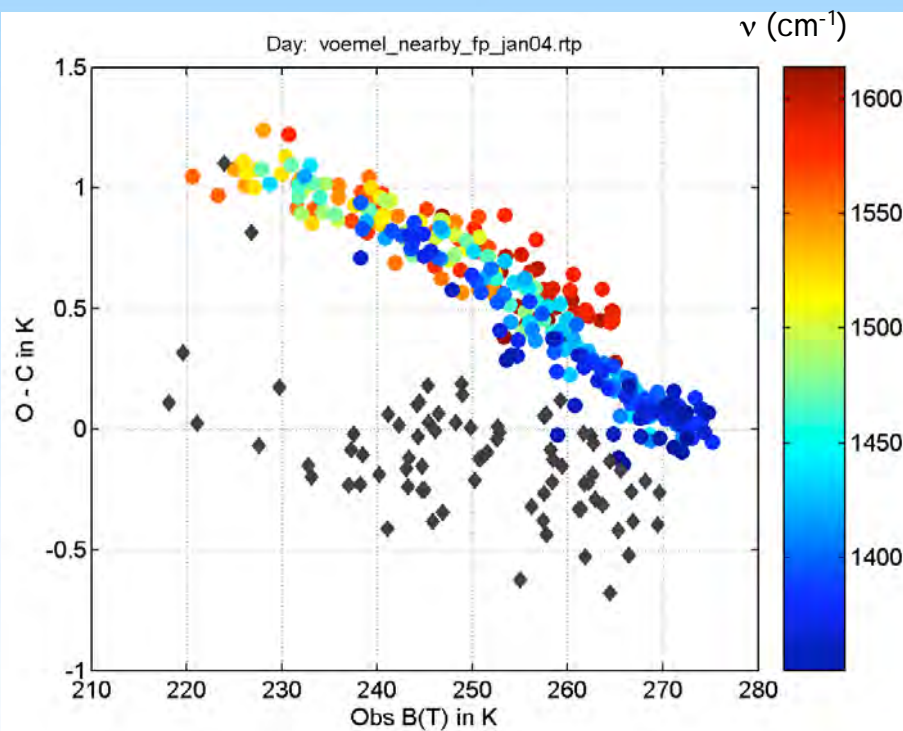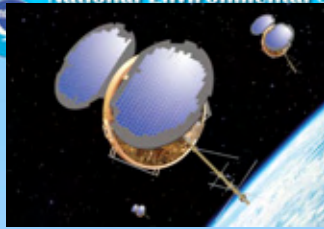
(ECMWF averaged over ~10-40 deg. Latitude)
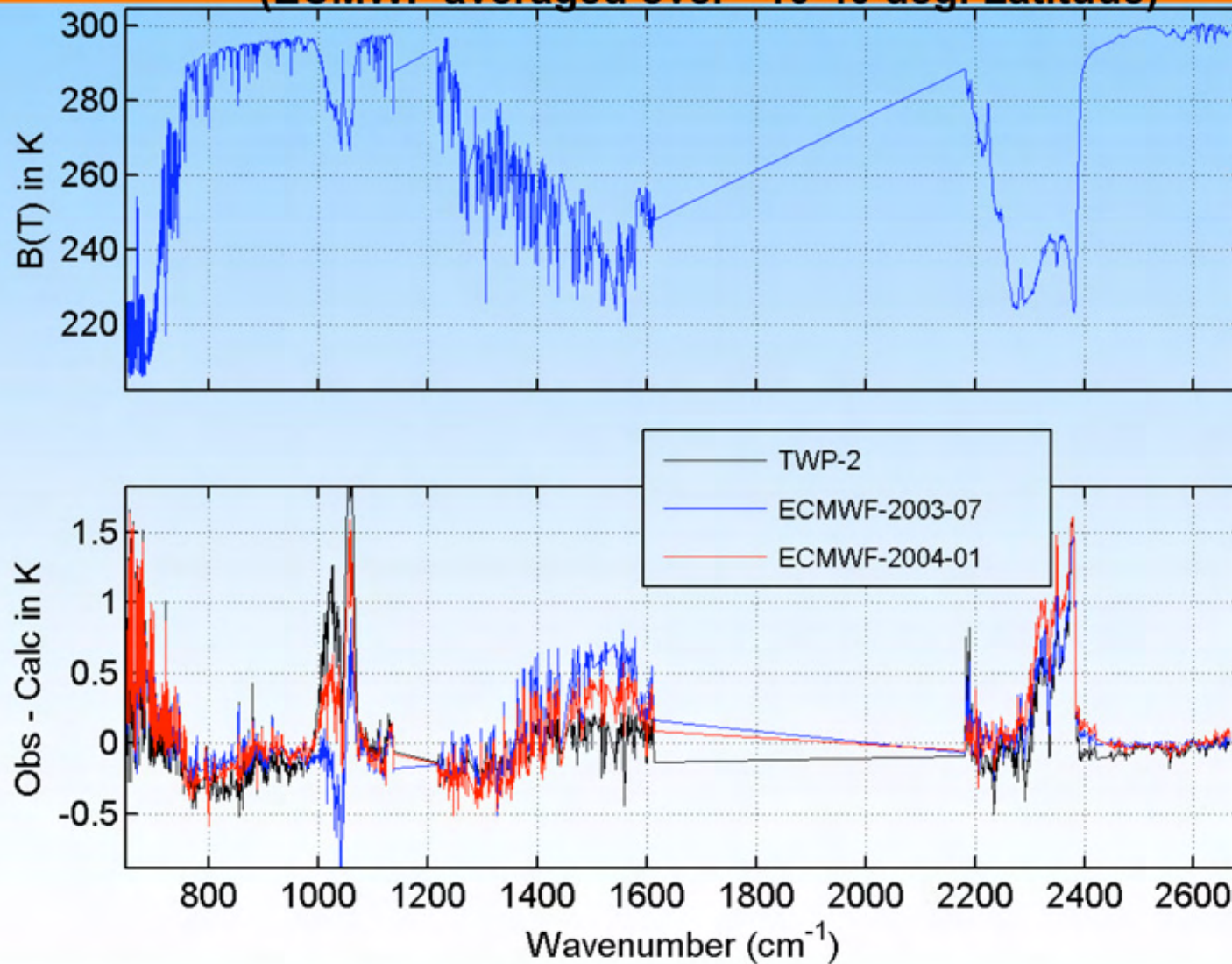
Frost-Point Observations Show Significant Deviations

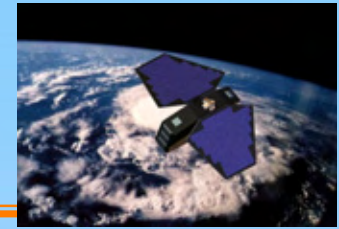Frost-Point Observations by
H. Voelmer: NOAA Boulder

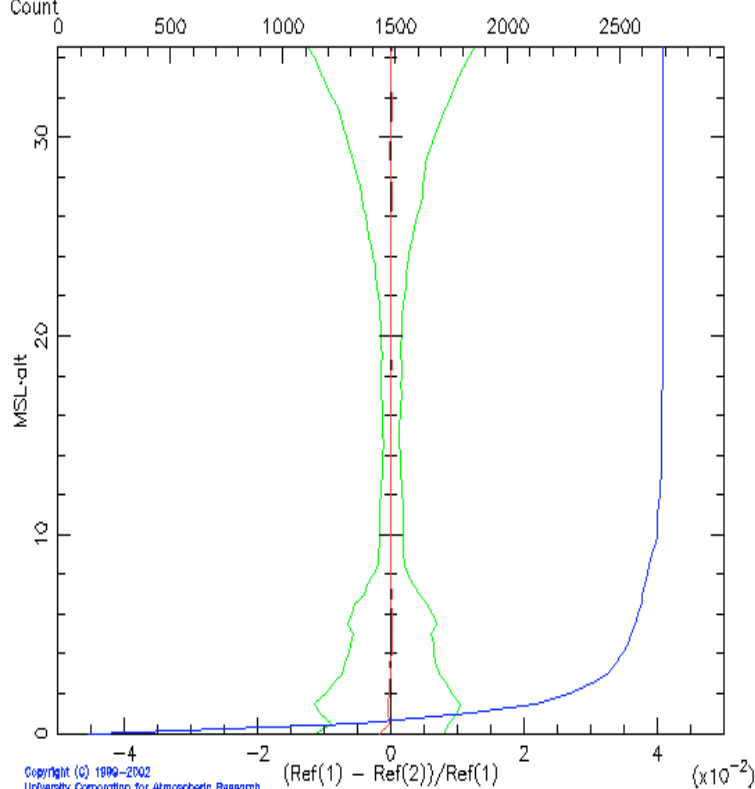Represents far fewer observations than RS-90's and inconsistencies day vs night.

Diamonds are CO_2 Biases for channels with similar peaking weighting functions.

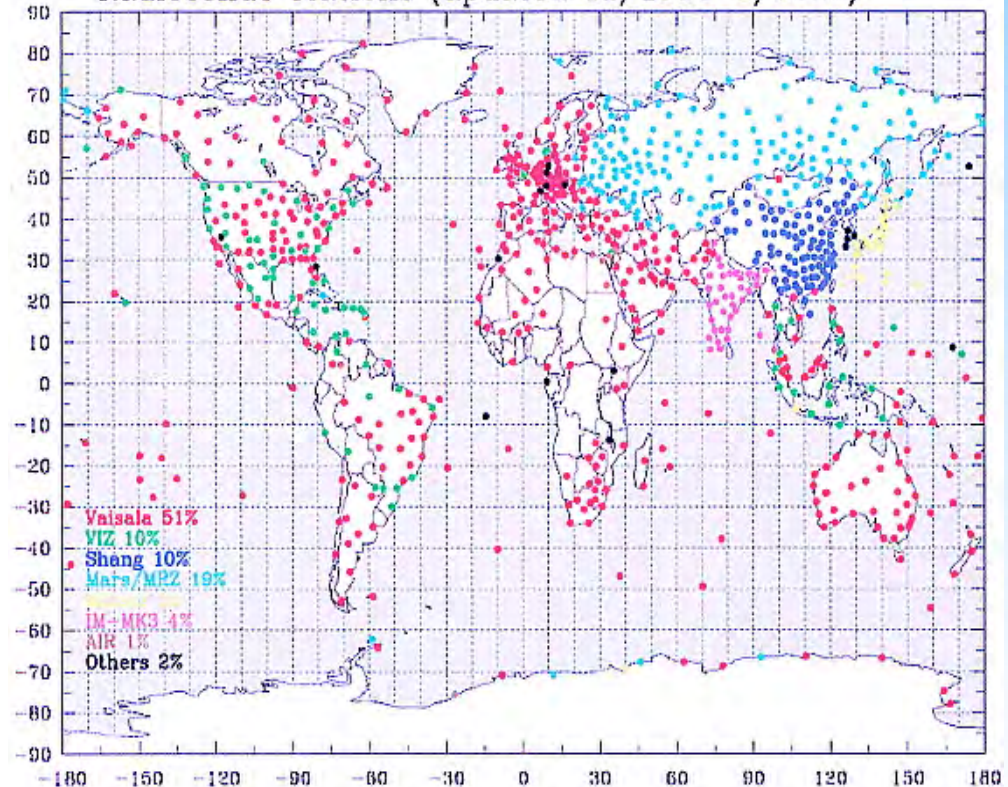# Global Radiosondes

COSMIC Colocations: Refrac., 2006.111-300, -90<LAT<90, DIS<10km

Radiosonde stations (updated 11/1996-2/2000)

Vaisala 51%
VIZ 10%
Shang 10%
Mars/MRZ 19%
IM-MK3 4%
AIR 1%
Others 2%

$$N = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{P_W}{T^2}$$

(Kuo et al., GRL, 2005)

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Shu-peng Ben Ho, UCAR/COSMIC

Mean Absolute Fractional Differences and Standard Deviation (S.D.) of Refractivity Between CHAMP RO Soundings and the Soundings From Five Different Types of Radiosonde System

Regions	Sonde Type	#of Matches	Del Nradio/S.D.	Del Necmwf/S.D.
India	IM-MK3	87	0.82/3.2	0.15/1.
Russia	Mars	1003	0.3/1.3	0.09/0.9
Japan	MEISEI	107	0.26/1.7	0.14/1.1
China	Shanghai	402	0.19/1.4	0.15/1.0
Australia	Vaisala	366	0.18/1.3	0.13/0.9

GSICS Outcome

- Coordinated international intersatellite calibration program
- Exchange of critical datasets for cal/val
- Best practices/requirements for monitoring observing system performance (with CEOS WGCV)
- Best practices/requirements for prelaunch characterisation (with CEOS WGCV)
- Establish requirements for cal/val (with CEOS WGCV)
- Advocate for benchmark systems
- Quarterly reports of observing system performance and recommended solutions
- Improved sensor characterisation
- High quality radiances for NWP & Climate